STORIES OF SCIENTIFIC DISCOVERY

BY

D. B. HAMMOND

FORMERLY SCHOLAR OF GIRTON COLLEGE, CAMBRIDGE

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TO THE PASTEURS, DARWINS, AND FARADAYS OF THIS GENERATION, AND TO ALL WHO TEACH AND INSPIRE THEM, THIS BOOK IS RESPECTFULLY DEDICATED

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PREFACE

SOME years ago, while teaching Chemistry and Physics to a class of boys between the ages of 15 and 17, I introduced some biographical details about Priestley and Lavoisier and was pleasantly surprised at the interest shown. This led me to wish to learn something of the lives of other great scientists, and having at the time no leisure in which to read long biographies, I enquired from various publishers for a collection of short biographical sketches. To my surprise, I failed to find just the book I was seeking, and in talking to other members of the teaching profession, men and women, I found that they too had desired, but had not found, the type of book I wanted. At about this same time I read the Science Report[1] and noticed that it recommends that the teaching of science, both in schools and among adults, should be "vivified by a development of its human interest." This recommendation and the demand on the part of teachers made me think of trying to supply the lack myself, and coming later upon a period of comparative leisure after the War, I decided to read the standard biographies of a few of the greatest scientific discoverers and to make from them a series of short sketches, suitable either for

[1] *Report of the Committee appointed by the Prime Minister to enquire into the Position of Natural Science in the Educational System of Great Britain.*

use in schools or for members of the general public, who, while interested in the lives of scientists, are too busy to study the fuller originals. Such a method of treatment has the advantages and disadvantages of an advertisement; the elimination of many details means that what is left is easily seen and some sort of general impression obtained at a glance, but it means also that the reader is peculiarly at the mercy of the writer, who has selected the details that remain. My only claim to a hearing is that I have felt for each man and woman of whom I have written a sense of personal friendship, and, if this book does no more than act as an advertisement for the fuller biographies and give to its readers also the chance of widening the bounds of their friendship and sympathy, it will have served a useful purpose.

In the vast field of scientific discovery, the choice of eight or ten names from the great number of those whose work places them in the front rank was necessarily difficult, and some plan to guide selection had to be made. It was therefore decided to choose, as far as possible, one representative of each branch of science with which those who have had a good general education are likely to be familiar, and then, from among the possible candidates, to choose the man or woman whose life had special human or dramatic interest. Priestley and Lavoisier, for instance, are chosen rather than Cavendish to represent the Chemical Revolution because their lives are incomparably more interesting on the non-scientific side; Rumford is chosen

to represent Heat on account of his adventurous life, and Fabre to represent Nature Study because of the charm of his personality. No apology is needed for including Darwin and Wallace in a book of this kind, for their theory of Natural Selection marks an epoch in the biological sciences. For a similar reason, Pasteur and the Curies are among those chosen; for though the full import of their discoveries can only be appreciated by specialists, their researches also form starting-points for new lines of thought and investigation, and moreover have an added claim on our interest and admiration from the fact that they were carried through in face of grave personal risk.

No standard life of the Curies has yet been written, and, owing to the retiring nature of Mme Curie, reliable information of a personal nature about her and her late husband is difficult to obtain. Most of the details in my description of them are taken from an article by their friend and fellow-worker, Paul Langevin, and are therefore, I hope, substantially accurate. Should the picture I have tried to draw seem to friends of the Curies to give, by any errors of fact or false emphasis, an incorrect impression, I offer to them my sincere apologies. Of two evils, the risk of minor inaccuracies seemed to me less than the loss to the book by omitting an account of their life of happy and fruitful co-operation.

Various friends have encouraged me by interest in the general idea of my book and my husband has acted as helper and critic in all its stages. My

thanks are, however, in a very special measure due to Miss E. D. Bradby, who has read my MS. and given me much helpful criticism, and to the late Mr J. B. Peace, whose experienced advice, more particularly on the subject-matter of the chapters, has been invaluable.

D. B. HAMMOND.

June, 1923

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INTRODUCTION

Produce great Persons and the rest follows.

WALT WHITMAN.

Our material life, all that we see, and hear, and touch, and use, has issued from pensive minds and brooding hearts.... All the magnificence, all the power, all the innumerable commonplace blessings which we enjoy daily without thinking, were born in the silent thoughts of single lives.

JAMES A. MACKERETH.

A WRITER of the nineteenth century tells a gruesome tale of an ingenious person who created a mechanically perfect semblance of a man and then found, to his horror, that he could not control it; instead of mastering the creature of his brain he was mastered by it, this man that yet was not a person. There is some danger lest the modern world should, in the same way, allow itself to be unduly impressed by its own mechanical skill and material progress and to forget that the most wonderful and inexplicable phenomenon on this earth is still human personality. So much knowledge has been collected and tabulated and so many theories of the workings of nature have already occurred to men in the past, and are now to be found in every text-book, that it is easier for the twentieth century than it was for the nineteenth to ignore the human lives and personal endeavour that have gone to the making of our western civilisation.

This aspect of science is further obscured by the narrow view, peculiarly common at present, that every branch of learning must immediately prove

its usefulness or be condemned, that every man must show himself to be a "practical man" or be content to be thought a fool. "What is the use of it?" is the stock question about a new discovery, and one wishes there were more Faradays in the world to retort with the *mot juste*, as when, in reply to this same question from Gladstone, who as a scholar and statesman ought to have known better, he answered, "Why, sir, there is every probability that you will soon be able to tax it."

In each generation it is necessary to combat this view. Pasteur, speaking to a class of technical students at Lille in 1854, reminded them that: "Without theory, practice is but routine born of habit. Theory alone can bring forth and develop the spirit of invention. It is to you specially that it will belong not to share the opinion of those narrow minds who disdain everything in science that has not an immediate application."

In our own day Mr G. K. Chesterton has taken up the cudgels and attacked the enemy in his own whimsical way:

> There has arisen in our time a most singular fancy—fancy that when things go very wrong we need a practical man. It would be far truer to say that when things go very wrong we need an unpractical man. Certainly, at least, we need a theorist. A practical man means a man accustomed to mere daily practice, to the way things commonly work. When things will not work, you must have the thinker, the man who has some doctrine about why they work at all. It is wrong to fiddle while Rome is burning; but it is quite right to study the theory of hydraulics while Rome is burning.

As we read the lives of great scientists, we find that this is literally true. Count Rumford spent his life translating his theories into terms of practical efficiency; Pasteur exterminated the silk-worm disease in France after the experts had failed; and Madame Curie, a woman and a laboratory scientist, was entrusted by the French Government with supreme control of the work in radiology in their military hospitals during the Great War.

The practical results of the discoveries of these people were sufficiently obvious to ensure them prompt recognition; but others equally great have been scorned, persecuted, or ignored by their contemporaries, and it is still unfortunately true to say that the general trend of western civilisation is towards a rapid and superficial efficiency and that the popular hero is "the man who gets things done." There is no reason why this should always be so; in the East the man who lives a life of thought and meditation is ranked above his fellows, and in time a wider culture and knowledge of other races may restore him to his proper place in the West also. Our minds are naturally more practical than the Eastern and more afraid of thought, but the present over-emphasis on material success is undoubtedly a passing phase. From this only the idealists, who exist in East and West alike, can rescue us, and this they will do most easily by touching, as Fabre did, "the warm hearts and cheerful imaginations" of the rising generation while they are still "overflowing with that springtide sap of life which makes us so expansive, so desirous of knowledge."

Meanwhile, all but the privileged few have to conform to the views of the majority and spend the years that should be used for the education of the whole personality in feverishly preparing for some highly specialised work, or feverishly taking their pleasures in some form that makes no demand on the tired brain. In a recent *Punch* cartoon a boy is sitting with a book in his lap, but unable to give his mind to it because round him the familiar cinema figures swarm, distracting his attention. Modern conditions make it difficult for even a literary boy or girl to "browse" in a library, taking down a dusty two-volume biography and spending a morning in the company of some great writer, statesman, or scientist; and, in later life, many men and women who have a real taste for reading the lives of inspiring characters have little leisure, and so can only make the acquaintance of a select few. Among these, the great scientists have hardly had their due place; and yet, in this age of science, it should be of special interest to discover what manner of men they were. When Monypenny's *Life of Disraeli* appeared, *Punch* depicted two young politicians as poring over it:

First speaker: "Master of epigram—like me!"
Second speaker: "Wrote a novel in his youth—like me!"
Both together: "Travelled in the East—like us! How does it end?"

So might two young scientists pore over the biography of one of their great predecessors, interested to find in his early life points of resemblance with their own and eager to discover the secret of his

success. The discovery of this secret is not only of interest but of the first importance, for we have lost something which these earlier scientists had. If we can discover their secret, we are at least on the road to following in their footsteps.

Now, as we read the lives of the pioneers of science, what strikes us most at first is that they are not all of one class or type. Count Rumford, through his own efforts, and Lavoisier, through his father's, moved in high circles and held important state appointments; Faraday and Fabre were both self-educated sons of the people, disliking the limelight and finding their happiness in their work and family life; Cavendish belonged to the famous House of Devonshire and was a notorious misanthrope; Darwin was the son of a doctor and in early life had many of the tastes of a sporting country gentleman. Here is no common ground of inheritance or opportunity or culture, only an inborn interest in science linking these men together. In their attitude towards their gift, however, there is a quite remarkable resemblance. One's first thought on turning over the pages of a biography may be "How does it end?", but it ought rather to be "How does it begin?" The inspiration, whether to be a poet, a painter, a discoverer, or whatever it may be, does not seem to be a matter of choice—a Newton cannot choose to be a Shakespeare, a Madame Curie cannot choose to be a Joan of Arc—but all can choose to be or not to be their greatest selves, and the choice is most effective when made in youth. For this choice

courage is always needed and only those who show it can enter into their heritage. Darwin might have been a rather indifferent country doctor, glad of any excuse to take a day off with a sporting friend, Pasteur might have been a tanner in a little provincial French town, and Fabre a small farmer on the "cold granite ridge of the Rouergue tableland," if they had not had the courage to follow their own individual tastes in spite of the disapproval or misgivings of their relations. The first point, then, that these pioneers have in common is that *they were not afraid to be themselves.*

Given the inspiration and given the courage, however, something more is needed, and that is patience and the power of sustained hard work. Genius is not merely "an infinite capacity for taking pains," but, without that capacity, the flashes of inspiration that come to it would be like the spurt of a match on a dark night, which, finding no fuel at hand, dies out and does little to warm and light the world. Pasteur at one of the most critical moments of his life said that he had "a lasting provision of faith and fire." The first spark was the divine gift, but the steady flame was fed by his own unremitting labours. It is just this combination of "faith and fire" with sustained mental effort that we lack to-day, and this is not merely a loss to ourselves but a danger to the whole world. Pasteur "looked upon the cult of great men as a great principle in national education," and it is a principle worth trying, for our hope lies with the young. If their hearts can be touched and their

minds inspired by the personalities of ardent souls in their own and past generations, they will fulfil their high destiny, while the "immortal dead" will

live again
In minds made better by their presence; live
In pulses stirred to generosity,
In deeds of daring rectitude, in scorn
For miserable aims that end with self,
In thoughts sublime that pierce the night like stars,
And with their mild persistence urge man's search
To vaster issues[1].

[1] George Eliot: "O may I join the choir invisible."

PRIESTLEY AND LAVOISIER AND THE CHEMICAL REVOLUTION

> If each of us adds something to the common domain in the field of science, of art, of morality, it is because a long series of generations have lived, worked, thought and suffered before us.
>
> BERTHOLLET.

EVERYONE who has been in a school laboratory has probably, at some time or another, been given a series of unknown substances, with directions to heat them in test-tubes and note all that happens. In this series mercuric oxide is usually included and is generally popular, because something certainly happens—something quite unexpected and yet quite easy to notice. It is both surprising and interesting to see this brick-red powdery substance darken in colour, and then, when the attention shifts for a moment to the upper part of the tube, to notice the metallic mirror forming there. If the budding chemist has not previously studied the "preparation and properties of oxygen" *ad nauseam*, his curiosity will also be aroused by the re-lighting of a glowing splinter of wood held at the mouth of the test-tube, and will later on be, partially at least, satisfied by information about oxides, oxidation, reduction, and other kindred matters. Yet how many people let their spirit of enquiry carry them deeper, and ask how this information was in the first instance obtained?

In the City Square in Leeds are statues of some of her leading men, and among them is one of

Joseph Priestley, holding in one hand a large magnifying glass. Who was this Joseph Priestley and why does he stand there with his burning-glass for future generations to see? Other men look down on us from stained-glass windows, holding the churches they have built; others again stand, sword drawn, our perennial champions on the field of battle; still others—statesmen these—lift persuasive hands in silent reminder of their oratory. Each figure marks some triumph and achievement. For what victory, then, do that burning-glass and quiet, kindly figure stand?

Joseph Priestley (1733–1804) was the son of a cloth-dresser in Fieldhead, near Leeds. His mother died when he was seven, and from that age he was brought up by an aunt, a Mrs Keighley, described as a "pious and excellent woman in a good position, who knew no other use of wealth, or of talents of any kind, than to do good." The Calvinism prevailing in his aunt's circle somewhat overshadowed his early life, but his vigorous mind and kindly and sociable nature saved him from its excesses and launched him on the world a keen but tolerant theologian. Following his own and his aunt's wishes for him, he became a preacher. In this profession he was handicapped by a stutter and by views too broad for his somewhat narrow hearers; he had periods of great financial anxiety, but, with characteristic pluck and optimism, survived them and, whenever circumstances allowed, devoted himself to the experiments he loved and from which he obtained such remarkable results.

In the first half of the eighteenth century scientists had no clear notion of the existence of numerous gases as distinct from each other as the solids and liquids that had long been systematically studied. The term "gas" was first used by Van Helmont, and Boyle and Mayow knew that there were various forms of "air," but considered them as being fundamentally the same, only "infected" or "tainted" with "extraneous fumes." Stephen Hales, who first adopted the familiar method of collecting "airs" over water, the jars being suspended by means of string, investigated the properties of many common gases, but did not escape from the current idea of a "universal air, elementary and primordial." The credit of freeing scientific thought from this crippling notion is due in a measure to Black, who wrote about the middle of the century, but to an even greater degree to the work and writings of Henry Cavendish, that strange misanthropic offshoot of the Dukes of Devonshire, to whom "the pursuit of truth was a necessity, not a passion." In 1766 Cavendish published *Three Papers, containing Experiments on factitious Air*, meaning by factitious air "any kind of air which is contained in other bodies in an inelastic state, and is produced thence by art." These papers contain an account of numerous experiments on the production and properties of many gases, of which the most important dealt with are "inflammable air" (hydrogen) and "fixed air" (carbon dioxide). Cavendish, like Hales, collected his gases over water in jars held up by string, and then pro-

ceeded to study their properties; and in this way he established beyond question the fact that there are numerous "elastic fluids differing essentially from common air." The publication of these papers greatly stimulated interest in the study of gases and—as Thorpe writes in a biographical sketch of Cavendish—"no doubt influenced Priestley in choosing this branch of chemical enquiry for his first essays in original investigation, thereby leading to a great extension of our knowledge of gases, and eventually to a complete revolution in chemical doctrine."

Priestley was essentially a man who, like many a great man before and since, converted the difficulties of his life into helps by the way. Cavendish could devote his whole time and wealth to science and was, as Biot said, "le plus riche de tous les savants et le plus savant de tous les riches"; Priestley was always a poor man with scant leisure, yet he saw in his lack of chemical appliances and of money to buy them the secret of some of his successes. "If I had been previously accustomed to the usual chemical processes," he says, "I should not have so easily thought of any other, and without new modes of operation I should hardly have discovered anything materially new." Of his ideas for practical contrivances perhaps the most generally useful is the simple one of putting a shelf, as we have it to-day, below the level of the water in a pneumatic trough, and so doing away with the clumsy arrangement employed by Hales and Cavendish. This invention earned for him the title of

"Father of Pneumatic Chemistry," and, though this might more justly be given to Hales or Cavendish, it remains true that he revolutionised the chemical ideas of his day.

But what of the burning-glass? Let us come back to that and hear, in Priestley's own words, what part it played in this Chemical Revolution. "At the time of my former publication I was not possessed of a burning-lens of any considerable force; and for want of one I could not possibly make many of the experiments that I had projected....But having afterwards procured a lens of 12 in. diameter and a variety of substances I proceeded with great alacrity to examine by the help of it what kind of air a great variety of substances would yield."

Priestley had his various substances supported in closed vessels standing over mercury, and we can picture him eagerly walking round his laboratory and concentrating, by means of his longed-for lens, the heat of the sun on one after another of the substances. "On August 1st, 1774," he goes on, "I endeavoured to extract air from mercurious calcinatus per se [mercuric oxide] and I presently found that, by means of this lens, air was expelled from it very readily....But what surprised me more than I am well able to express was that a candle burned in this air with a remarkably vigorous flame. I was utterly at a loss how to account for it."

From red lead he also obtained this air that is similar to, but, as he expressed it, "better than," common air.

The goodness of the air he examined by two tests. In the first, a candle was introduced into a closed space containing the air; if it burnt more brightly and for a longer time than it would have done if the space had been filled with atmospheric air, the gas was said to be better than common air. In the second, a mouse was shut up in a jar of the gas and the length of time it lived in it was noted; if it lived longer than another mouse in a similar jar of ordinary air, the new gas was, again, better than the air, and the ratio of the times taken by the two unfortunate mice in dying was considered a measure of the goodness of the gas. Priestley himself breathed some of his new gas and described his sensations as follows: "I fancied that my breast felt peculiarly light and easy for some time afterwards. Who can tell but that in time this pure air may become a fashionable article of luxury? Hitherto only two mice and myself have had the privilege of breathing it."

Fortunately, oxygen has not been added to the list of the luxuries of the rich; but its administration in cases of great exhaustion and serious illness has saved many lives, and its commercial and other practical uses are too numerous to mention.

In 1772 Priestley had been appointed "literary companion" to Lord Shelburne; this position involved little work and relieved him from financial embarrassments, and in 1774, we read, he travelled on the Continent. This holiday had important scientific results, as it brought him into touch with Lavoisier, the great French chemist.

Antoine-Laurent Lavoisier (1743–1794) was born a member of the *tiers état*, but his father bought a place which conferred nobility on himself and his descendants and so ranked as an aristocrat. The family was not wealthy but was sufficiently rich to send him to the Collège Mazarin, where the inspiring teaching of Rouelle first turned his thoughts to chemical problems. Although chemistry was from this time the first enthusiasm of the young Antoine's life it was never the exclusive one. We must picture him working for the public good not only in the laboratory, where disinterested motives are common enough to be taken for granted, but also in the dusty arena of politics, where the man of high ideals and honest purpose is so often, as in Lavoisier's case, misunderstood and condemned.

In 1768 two important events took place in Lavoisier's life; he became Adjoint of the Académie des Sciences and also Adjoint of the Ferme-général. His connection with the Academy had of course important bearings on his scientific career; the other connection, accepted partly for financial reasons and partly from public-spirited motives, proved disastrous.

The Ferme-général consisted of a body of financiers who received from the State a fixed annual sum and in return collected the indirect taxes of the country. In the hands of unscrupulous men, this system gave endless opportunities for unfairness, petty tyranny, and misuse of public money. In the reigns of Louis XIV and Louis XV all these abuses existed, and the organisation was justly de-

tested by all who did not reap comfortable profits from it. The size of Lavoisier's modest fortune was insufficient to meet the claims made on it by the scientific work he had planned, and this no doubt influenced him to listen to the advice of a family friend and to become Adjoint of the Fermier-général Baudon, in return for a third of his profits. His fellow-members of the Académie des Sciences regarded his action with very natural misgivings; but their fears at first seemed groundless, for Lavoisier proved himself able to pursue his scientific career and at the same time to do his work for the Ferme-général. There were of course many honourable fermiers-généraux, and Lavoisier was among them; he did his best to relieve France of some of the worst evils of the system, but its earlier history was never forgotten, and at the last its would-be reformer was involved in its fall.

Two years before Priestley came to Paris, Lavoisier had deposited with the French Academy a sealed packet containing a record of some of his scientific work—experiments showing that tin and lead gain in weight when heated and that sulphur and phosphorus become heavier when they burn. He also proved that the gain in weight was accompanied by absorption of some of the air.

The importance of these experiments and of Lavoisier's later work can hardly be realised without a brief reference to some of the chemical ideas of the day. In all scientific work an experiment is judged not chiefly by its individual interest but rather by the help it gives us in forming a general

idea of the nature of substances and processes. Some people consider that Priestley did not sufficiently emphasise this side of his work, and yet this is what he himself says in the matter: "It is always our endeavour, after making experiments, to generalise the conclusions we draw from them, and, by this means, to form a theory or system of principles to which all the facts may be reduced and by means of which we may be able to foretell the results of future experiments."

Chemists from the earliest days had known that most metals when heated change their appearance and many other characteristics; the altered metal was called a "calx" and the process "calcination." Other substances—wood, coal, wax, etc.—when heated burn and, to a greater or less degree—to use a popular expression—burn away. Some metals burn if heated strongly, while, if heated more gently, they give no flame, and yet the final product is in both cases the same. Chemists therefore regard burning and calcination as essentially the same process, and the problem is to find some theory to explain both.

Becker, in the middle of the seventeenth century, suggested that all combustible substances contain "something"—*terra pinguis* he called it—which, when they burn, escapes. A pupil of his, Georg Ernst Stahl, developed this idea and converted the scientific world of his day to his ingenious Phlogiston theory. Becker's "something" he called Phlogiston; when metals are calcined or other substances burnt, they lose Phlogiston; when a calx is

converted into a metal, Phlogiston is absorbed. The theory explains simply and well the complete or partial disappearance of many substances on burning. How, though, does it fit in with the results of Lavoisier's experiments on the heating of lead and tin? If a metal loses Phlogiston on being calcined, surely it should also lose, not gain, weight. The upholders of the Phlogiston theory had had to meet this difficulty before, and did so by supposing that Phlogiston possessed "levity" rather than weight and so buoyed up a substance containing it. The second fact, of the absorption of air during calcination, was harder to explain.

Perhaps without Priestley's visit the full significance of this would have escaped Lavoisier's notice. Some eager partisans trumpet one man's claims and some the other's—who can say how much of our work is ours and how much another's? Priestley, stuttering out enthusiastically the results of his surprising experiment to his eager listener, certainly never gave the matter a thought. Let us be content to think of both men as links in the great chain of those who have added "something to the common domain in the field of science."

Lavoisier's experiments showed that calcination is accompanied by absorption of air; Priestley's that the reverse process—the recovery of the metal from the calx—yields air. According to the Phlogiston theory, however, something—Phlogiston—is in the first case liberated and in the second absorbed. Lavoisier saw whither these facts pointed and devised and carried out a convincing and mas-

terly experiment which has since become historic. Here is a description of it in his own words.

Taking a vessel, or long-necked tube with a bell or globe at its extremity, containing about 36 cubic inches, I bent it so as to place it in the furnace whilst the extreme end of the neck was under a glass cover, which was placed in a basin of mercury. Into this vessel I poured 4 ounces of very pure mercury, and then, by means of a syphon, I raised the mercury to about three-quarters the height of the glass cover, and marked the level by gumming on a strip of paper.

I then lighted the fire in the furnace, and kept it up incessantly for twelve days, the mercury being just sufficiently heated to boil. At the expiration of the second day, small red particles formed upon the surface of the mercury, and increased in size and number for the next four or five days, when they became stationary. At the end of the twelve days, seeing that the calcination of the mercury made no further progress, I let out the fire and set the vessels to cool. The volume of air contained in the body and neck of the vessel before the operation was fifty cubic inches and this was reduced by evaporation to forty-two or forty-three. On the other hand, I found, upon carefully collecting the red particles out of the liquid mercury, that their weight was about forty-five grains. The air which remained after the operation, and which had lost a sixth of its volume by the calcination of the mercury, was no longer fit for respiration or combustion, as animals placed in it died at once, and a candle was extinguished as if it had been plunged into water.

Taking the forty-five grains of the red particles, and placing them in a small glass vessel, to which was adapted an apparatus for receiving the liquids and aeriform bodies which might become separated, and having lighted the fire in the furnace, I observed that the more the red matter

became heated the deeper became the colour. When the vessel approached incandescence the red matter began to become smaller, and in a few minutes had quite disappeared; and at the same time forty-one and a half grains of mercury became condensed in the small receiver, and from seven to eight cubic inches of gas, better adapted than the air of the atmosphere to supply the respiration of animals and combustion, passed under the cover.

Lavoisier, in the first part of his experiment, deprived the air in his glass cover of its active constituent; in the second, he obtained an active gas from his red particles. More than this, the diminution in volume in the first part of his experiment—from fifty to forty-three cubic inches—was the same as the volume of gas produced in the second. The chain of evidence was almost complete; it only remained for Lavoisier to introduce the gas obtained from the red particles into the original glass cover, and behold it contained once more fifty cubic inches of ordinary air!

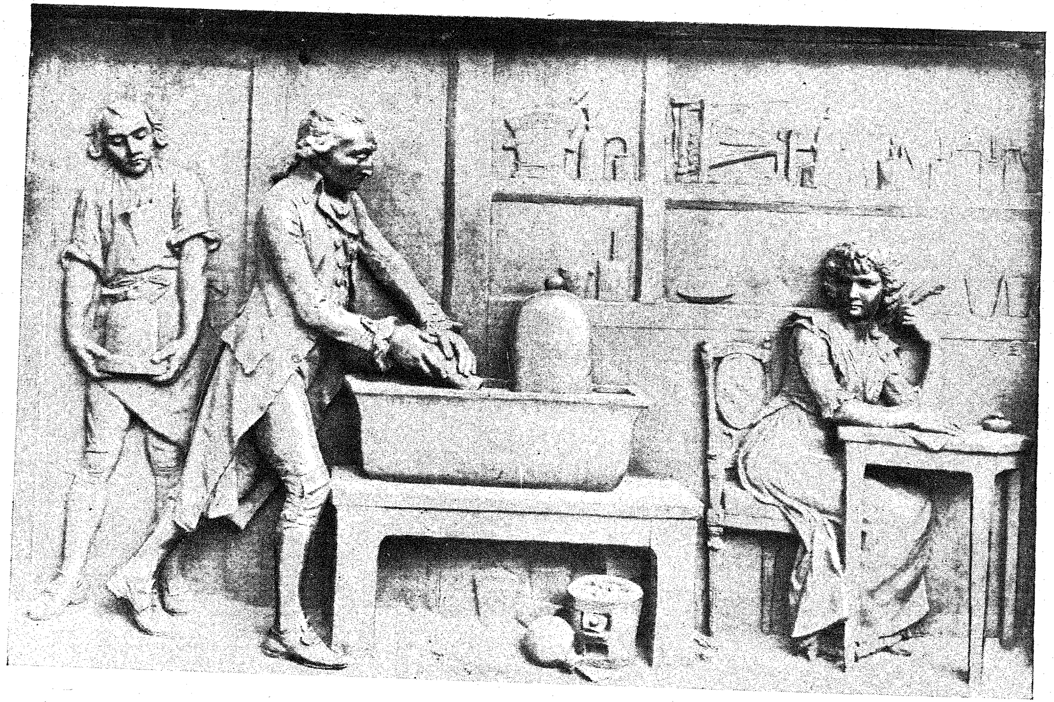
The second section of this experiment is, in essence, Priestley's; but Lavoisier's work was an advance on his, because he combined the reverse processes in a single experiment and because he drew such clear and convincing conclusions: "From the consideration of this experiment we see that the mercury, while it is being calcined, absorbs the only portion of the air fit for respiration, or, to speak more correctly, the base of this portion, and the rest of the air which remains, is unable to support combustion or undergo respiration. Atmospheric air is, therefore, composed of two gases of different, and even opposite, natures."

The facts disclosed by Lavoisier's experiment could all be accounted for in terms of the Phlogiston theory, but only by making clumsy additions to it which spoilt its earlier attractive simplicity. A scientific hypothesis is only healthy and respectable when it explains a greater number of facts in a more convincing way than any other rival hypothesis. Lavoisier and his friends were ready with a more satisfactory theory, and Phlogiston was from that moment indeed a thing without weight.

Lavoisier's conceptions of the nature of combustion and of the constitution of the atmosphere are, in essence, those held to-day. Air, he said, consists of an active and an inactive portion; the former—to which he gave the name "oxygen"—is necessary for breathing, for the calcination of metals, and for the burning of numerous other substances. The calx of a metal is heavier than the metal, because oxygen has been added to it. His researches led him, further, to the important generalisation that, in chemical actions, "nothing is lost, nothing created—matter is indestructible."

More than a century has passed away, and these two hypotheses, as to the nature of combustion and the indestructibility of matter, have been tested by numerous experiments. They have stood the test and Lavoisier has been proved worthy of his proud title of "Founder of Modern Chemistry."

And, meantime, while we have been watching Priestley and Lavoisier at work in their laboratories, what of the world of thought and action outside? Everywhere thought was stirring; the



ANTOINE LAURENT LAVOISIER AND HIS WIFE

old-established things were being undermined, old abuses were being attacked, old modes of thought were being questioned. Such an atmosphere is life-giving to bold and broad-minded thinkers, but in it the lawless and unbalanced flourish also. It fostered the broad-minded spirit which led Revolutionary France to admit, in August 1792, Priestley and other distinguished foreigners as French citizens, but it bred also the base passions which, in May 1794, sent Lavoisier to his death. In England both extremes were less strongly marked, but there too a spirit of tolerance was growing, though marred at intervals, as in France, by revivals of bitter party strife.

In one of these unhappy spasms of party feeling, an excited mob attacked and wrecked, in the name of "Church and King," the houses and chapels of leading dissenters in Birmingham. Priestley had, some years before, accepted the charge of a congregation in that city; he was happy in his religious and scientific work and in the possession of many congenial friends, and his writings at this time show a deep sense of peace, security, and thankfulness. Across this calm the rioters broke cruelly. He and his family escaped unhurt, but home, library, and scientific apparatus were lost. Some friends stood staunchly by him, but his countrymen generally were hostile; and at last, sadly, but without bitterness, he decided to go into exile. Birmingham and Leeds have erected statues in his honour, but America has the proud privilege of guarding his grave.

And what, meanwhile, was France doing with

her prophet of the Chemical Revolution? Lavoisier was not a politician, in the narrow partisan sense, and had for years devoted his knowledge and much of his time and money to work for the State; but all this disinterested service counted for nothing when the shadow of the Great Terror fell on his unhappy country. The Académie des Sciences was a "monarchical institution"; the Académie therefore was suspect and must be suppressed. Lavoisier, as its treasurer, put in a passionate appeal for the continued support of those scientists who had grown grey in its service. The appeal failed, and merely served to concentrate the attack on Lavoisier himself. By an adroit move his enemies caused him, together with twenty-seven other fermiers-généraux, to be arrested. Men of eminence in the worlds of science and of public affairs pleaded for him, but in vain. On May 8th, 1794, in one of the most monstrous mock trials of the Revolutionary Tribunals, the twenty-eight fermiers-généraux were condemned to death. Modern research takes from us one by one our cherished sayings of History; but in this case the alleged answer to a final appeal on behalf of Lavoisier does, in fact, voice the attitude of the hour towards the things of the mind and spirit: "La République n'a pas besoin de savants."

The same day the guillotine silenced yet another of the voices of freedom and progress.

Books of Reference

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THE LIFE AND ADVENTURES OF BENJAMIN THOMPSON, COUNT RUMFORD

> It certainly requires some courage, and perhaps no small share of enthusiasm, to stand forth the voluntary champion of the public good. The enterprising seldom regard dangers, and are never dismayed by them; and they consider difficulties but to see how they are to be overcome. To them *activity* alone is life, and their glorious reward the consciousness of having done well. RUMFORD.

IT is the autumn of 1772, and the occasion is a great military display at Portsmouth, America. The unwise tyranny of Britain under George III is already straining the loyalty of her lusty young colony, but the open breach has not yet been made. The wealthy and cultured merchants of Portsmouth and the crown officers, "an aristocracy of influence and fashion," are gathered at this review in outward friendliness; but beneath the surface bitter feelings are fermenting. Life, however, has to be lived at many levels and this is a day of gaiety and display, and as such young Benjamin Thompson, one of the spectators, is taking it, enjoying to the full the fine figure he is cutting on horse-back and the notice he is attracting from Governor Wentworth and other people of fashion and distinction.

Throughout his life Benjamin Thompson the scientist and Benjamin Thompson the philanthropist are inextricably blended with Benjamin Thompson the courtier, the lover of social distinction, and, if we would understand him, we must not forget

this desire to be a gay and conspicuous figure prancing through life, raised above the rank and file and attracting general attention.

The Thompsons were a yeoman family, English originally but American since the seventeenth century, when a certain James Thompson is mentioned as being "a man of worth and position" in the town of Woburn, an off-shoot from Charlestown in Massachusetts. The father of the famous Benjamin, himself bearing the same name, married in 1752 Ruth Simonds, the daughter of "an officer who performed distinguished service in the French and Indian War," and took her back to his father's home in Woburn. There, on March 26th, 1753, the younger Benjamin was born and there less than two years later his father died. The young widow lived on with the grandparents for a time, and then, in March 1756, married Josiah Pierce and took her child to his home.

In later life Benjamin Thompson spoke as if his step-father had banished him from his home, but there is no evidence that this was the case. Four children were born to the Pierces, and it is quite likely that Josiah did not show as keen and individual an interest in Benjamin as his own father would have done; but there is no record of unkindness or neglect, and it is probable that Benjamin's own account was unconsciously coloured by his desire to attract sympathetic attention. His mother was devoted to him and from her he was certainly never estranged. His loving thought for her in later life is continually shown in his letters

and is marked in a practical way by the generous provision he made for her when he had become wealthy and famous.

Benjamin Thompson's early life and training were those of any boy in his circumstances; he attended the village school, and, having shown no aptitude for farming, was apprenticed at the age of 13½ to an importer of British goods, Mr John Appleton of Salem. As a schoolboy he showed a "particular ardor for arithmetic and mathematics" and spent much of his spare time, and some of what should have been his work-time, in experimenting with "ingenious mechanical contrivances"; and, as an apprentice, "instead of watching for customers over the counter, he was apt to busy himself with tools and instruments which he had hidden away under it." Like most boys with a scientific bent, he was fascinated by gunpowder, and he narrowly escaped blinding himself when his patriotic enthusiasm caused him to embark on the construction of fireworks for public rejoicings on the repeal of the Stamp Act.

The development of his mind after leaving school, however, was luckily not left entirely in his own inexperienced hands. "He was a handsome and engaging youth, of evidently bright faculties," and attracted the interest of the brother of a boy friend, Thomas Barnard, a young schoolmaster and minister, who taught him "algebra, geometry, astronomy, and even the higher mathematics" to such good purpose that before he was 15 he could calculate an eclipse. He was fortunate too in

possessing the friendship of Loammi Baldwin, a man nine years his senior, who shared his scientific interests and so was able to inspire and guide them. He proved a life-long friend, and Thompson's correspondence with him from the age of 15 onwards throws much light on both their characters.

In the autumn of 1769 Thompson was transferred to Boston as an apprentice-clerk to Mr Hopestill Capen, a dry-goods dealer. This move gave him the opportunity of attending a French school in the evenings; but by the following spring he had to leave this situation on account of the falling off of the business due to the non-importation agreement[1].

We next hear of this versatile youth as studying medicine under Dr Hay of Woburn, but he still found time to pursue science in other directions, and so great was his keenness that he and his friend Baldwin used to walk eight miles into Cambridge to attend some science lectures of Prof. Winthrop's at Harvard College. He seems to have taken his medical work seriously, but had to interrupt it periodically to earn money by teaching in schools or private families. His methods in the classroom were original—there are stories of athletic feats not confined to the playground—but evidently successful, and the offer of a good permanent post in a school at Concord decided him to abandon the medical for the teaching profession.

[1] "An agreement by which the mercantile and trading class in the Province sought to express their resentment...against the oppressive measures of the British Ministry."

Benjamin Thompson was by this time 19, "in the glory of his youth, not having yet reached manhood. His friend Baldwin describes him as of a fine manly make and figure, nearly six feet in height, of handsome features, bright blue eyes, and dark auburn hair. He had the manners and polish of a gentleman, with fascinating ways, and an ability to make himself agreeable. So diligently, too, had he used his opportunities of culture and reading that he might well have shined even in a circle socially more exacting than that to which he was now introduced."

First in this circle stood the Walkers—the Rev. Timothy Walker, first minister of Concord, his son, Col. Timothy Walker, a distinguished lawyer, and his daughter, recently widowed by the death of her elderly husband, Col. Rolfe, the wealthy squire of the place. Col. Timothy Walker had been the means of Thompson's coming to Concord, and it is not surprising that the fascinating young gentleman should soon have become a frequent and welcome visitor at the houses of both father and son, nor that the daughter, a widow at 30 after only two years of married life, should have fallen a victim to his charms. She seems to have taken the situation into her own hands; "I married, or rather I was married, at the age of 19," was Thompson's own terse and rather ungracious statement of the case years afterwards, but there is no reason to think that the marriage was unsuccessful. His wife's money gave him leisure for his scientific pursuits and her social position introductions to

distinguished and influential people. It was on *her* horse that he cut so fine a figure at the military display already mentioned and attracted the attention and the unwise patronage of Governor Wentworth.

A majorship in a New Hampshire regiment having just fallen vacant, Governor Wentworth offered it to Thompson, and he, flattered by the offer, foolishly accepted it. This naturally aroused the jealousy of the many experienced men who had a just claim to promotion, and when the final rupture between America and Great Britain came, this personal dislike no doubt helped to fix the suspicions of excited patriots upon Thompson. There is no evidence that at this time he took sides against his country, but he maintained friendly relations with Governor Wentworth and in other ways did not show the ardent partisanship expected of a patriot in time of war. On hearing that he was accused of "being unfriendly to the cause of Liberty," he gave out publicly that if his enemies would bring definite charges against him, he would meet them, and also that he was ready "to render any service for which he was fitted in the popular interest." Still no definite charges were made, but popular feeling against him mounted steadily, so that by November 1774 he was advised by Col. Timothy Walker to leave Concord.

He went first to his mother at Woburn, and there, for a time, his wife and baby girl joined him; but he was considered a suspect person and in May 1775 was arrested. After exasperating de-

lays his case was tried before the Committee of Correspondence for the town of Woburn, who found that in no instance had "said Thompson shown a Disposition unfriendly to American Liberty," but refused a public acquittal for fear of offending his accusers.

Nominally Thompson was now free to go where he liked and do what he would; but, for a man of his temperament, what prospects were there? He did not return to Concord. We hear of him at Woburn, at Charlestown, at Cambridge. He studied military tactics, he made further experiments with gunpowder, hoping against hope for a place "of honour and service in the patriot army." By August, however, he had realised the hopelessness of his position and determined, as he sadly wrote to his father-in-law, "to seek for *that Peace* and *Protection* in foreign Lands and among strangers which is deny'd me in my native country."

There was nothing secret about his departure. He settled his affairs, wrote affectionate and regretful farewells to his relations and friends, and, in October, set out, escorted by his step-brother, Josiah Pierce, to the bounds of the Province. In this way all the energy, resource, and ability that went to make up the complex personality of Benjamin Thompson were rejected by his native land and let loose for use against it. For he was no hero; he could never have responded to Garibaldi's appeal; he wanted service *and* honour; he could face death, but not death and obscurity. If loyalty to America had meant distinction, he would have

served her faithfully, but, as she slighted him, he sought for recognition, and transferred his loyalty, elsewhere.

Benjamin Thompson's first destination was England, and there he seems to have ingratiated himself at once with those in authority. The British Government, not for the first or last time in its history, was criminally and arrogantly ignorant of the state of affairs in its rebellious colony, and Thompson produced such useful knowledge, with such "gracefulness of manner," in his first interview with Lord George Germaine that this incompetent head of the Colonial Office promptly took him into his employment. What Thompson's private thoughts were we cannot tell, but by his public actions he now ranged himself on the side of Great Britain, and between the years 1775 and 1783 he held important civil appointments and even a military command which involved active service against his native country. It is hardly surprising that, for this period of his life, there is no trace of communications between him and his relations and friends in America.

While Thompson the courtier was "diligently and successfully cultivating the acquaintance of men of station and distinction" and Thompson the public servant was supplying the efficiency and information that these same "men of station and distinction" lacked, Thompson the scientist was busy also. His genius was practical rather than idealistic, and all through life he had a passion for "economy, utility and efficiency." He introduced

many improvements in military matters, continued his experiments on gunpowder, particularly in connection with naval artillery, devised a new code of marine signals, and pursued his scientific researches generally to such good purpose that in 1779 he was elected a Fellow of the Royal Society "as a gentleman well versed in natural knowledge and many branches of polite learning."

In 1781 his peaceful pursuits were interrupted by his despatch to the seat of war as Lieut.-Col. Commandant of the King's American Dragoons. This military campaign against his own people was a sad business, but he proved himself a brave and capable officer, and, on his return to England in 1783, was eager for further active service, preferably with his own regiment in the East Indies. The Peace rendering this unnecessary, however, he was made a half-pay Colonel for life and, further, given leave to visit the Continent, which he wished to do partly out of pure curiosity and partly in the hopes of finding there scope for his newly-acquired military ardour.

His career in Europe opened, as did his public career in America, with a horse-back display. A more restrained display, no doubt, suited to his greater age and experience—though he was still only 30—but equally successful in attracting the attention of the great. Prince Maximilian of Deux Ponts, afterwards Elector of Bavaria, commanding troops on parade at Strasburg, "sees among the spectators an officer in a foreign uniform, mounted on a fine English horse," speaks to him—and the rest

follows. The immediate result was that the Prince persuaded him to pass through Munich, giving him a letter of introduction to his uncle, the Elector. The five days Thompson spent in Munich were sufficient for him so to impress and charm the Elector that he invited him to enter his service in a joint civil and military capacity. This even Thompson could not do without permission from England, so thither he went in the spring of 1784 and soon returned to Bavaria with the required leave and a knighthood.

Thompson's new position called into play all his most characteristic qualities, and at no stage in his career did he show to better advantage. Casting his observant eye over the country, he saw everywhere waste and abuses, and his ingenious brain at once began devising remedies; yet he exercised both wisdom and patience in the task of what Prof. Gilbert Murray aptly calls "mobilising ordinary work-a-day motives" for his schemes of reform before attempting to put them into practice.

The standing army was a curse; the soldiers, badly paid, badly clothed, badly housed, regarded more or less as slaves by their officers, were so demoralised by their military training that they returned home "lazy loiterers." Thompson, seeing that the remedy lay "in making soldiers citizens and citizens soldiers," set about disseminating his ideas among the least callous of the officers to such good purpose that in four years' time he was able to introduce drastic changes which they believed they had themselves instigated. The pay of the

soldiers was raised, their clothing improved, and their barracks made clean within and beautiful without. Some of the more useless military instruction and discipline were abolished, schools were provided for the soldiers and their children, and each man was supplied with what we now call an allotment garden for his own private use and profit. This humane treatment, as is so often the case, proved also a public economy, for "indolent soldiers became model laborers," who were able to earn in such public works as the making of roads, the drainage of marshes, and so on, three or four times their pay and, when their military service was over, returned home good workmen and good citizens.

An even greater burden to Bavaria at this time than the standing army was the system of organised mendicancy, and Thompson's methods of dealing with beggars were as enlightened as those he used with the soldiers. "Precepts and punishments would be sure to fail, but they might be taught habits" and "made happy as a step towards making them virtuous." To realise this idea, Thompson secured a large, disused factory near Munich and fitted it up as a "Military Workhouse" with everything necessary for employing and feeding 1000 to 1500 people. All preparations made, he then proceeded to concoct a plan for catching his beggars. Hitherto New Year's Day had been regarded in Bavaria as the beggars' holiday but January 1st, 1790, Thompson decided should be the last day of begging in Munich. The officers and non-com-

missioned officers of the army were posted about the town and the field-officers and magistrates paired off and told to deliver every man who begged from them to a sergeant with orders to take him to the Town Hall. No violence was used, yet in this way every beggar was collected. They were all told to present themselves at the "Military Workhouse" next day and "promised there comfortable, warm rooms, a warm dinner daily, and remunerative work if they would labor." This plan was completely successful; the order in the factory, irksome at first to these former vagrants, ended by making them happy; and when on one occasion Thompson was seriously ill, the poor of Munich went in a body to the Cathedral to pray for his recovery. In a practical way, too, the scheme prospered. Forestalling the economies in cooking and household management forced on Europe by the Great War, Thompson made nourishing and, as he maintained, appetising soups of scraps collected from tradesmen in tubs labelled "For the Poor." He also introduced maize as an article of diet, and contrived to cook a dinner for 1000 to 1500 people with fourpence-halfpenny worth of fuel. All the clothing for 15 Bavarian regiments was made in the factory, and so much was sold besides that the profits for six years were over 100,000 florins.

During all these years of busy public work, Thompson's scientific activities continued. His first experiments in heat were performed at a foundry for cannon at Mannheim, and a foundry

built on more modern lines by him at Munich in connection with his army reforms was the scene, some years later, of his most famous discovery. His genius, as we have said, was essentially practical, one might almost say opportunist; ordinary daily happenings would suggest to him a line of investigation, and he could convert the most abstract discovery into some scheme of every-day usefulness. We have seen how he applied his scientific knowledge to kitchen economies, and the homely experience of burning his mouth with hot stewed apples led him to make experiments which proved that heat is not propagated in fluids, as was then thought, by conduction, but by the movement of the particles of the fluid or, as we should now say, by convection currents When the flow of these currents is prevented, as by the pulp in the watery fluid of the stewed apple, or by eiderdown in water, heat is not transmitted. He had already made this same discovery with regard to air and applied it to the problems of clothing, and his investigations on the relation between convection currents and changes of specific gravity led him to observe the remarkable variations of density of water near its freezing-point. This particular fact struck him as a "striking and palpable proof of the wisdom of the Creator, and of the special care he has taken in the general arrangement of the universe to preserve animal life." Self-assertive in other directions, he was in his scientific work humble, being, as he wrote, one of "those who, by cultivating their mental powers, HAVE LEARNED TO

KNOW HOW LITTLE CAN BE KNOWN." "There is nothing more dangerous in philosophical investigations," he says in his *Essay on the Propagation of Heat in Fluids*, "than to take anything for granted, however unquestionable it may appear, till it has been proved by direct and decisive experiment."

Turning again to Thompson in his public capacity, we see him in rather a different light, a little greedy of appreciation from those in high places, but still using his power in getting practical help for his schemes of reform as well as civil and military honours for himself. In 1791 the Elector made him a Count of the Holy Roman Empire, and it is pleasant to know that he chose the name Rumford, a former name for Concord, as his title; though his name had not been made in America, he would dedicate his greatness to her.

As time went on, the criticism of his institutions, which Rumford had at first so carefully disarmed, began to make itself felt; and the irritation caused by this, by the labour of management, and perhaps by unwise experiments in dieting on his own concoctions—for he is described as "whimsical about his food"—affected his health to such an extent that at last the serious illness already mentioned compelled him to seek rest and change. He was 16 months away from Munich, still ill but by no means idle. In Verona and many other cities he introduced his pet food and fuel economies, and in November 1793 he performed some heat experiments in the presence of Lord Palmerston at Florence. In August 1794, though not yet really well,

he returned to Munich; spent a year there in comparative quiet, writing a series of essays on a vast range of subjects varying from abstract problems in heat to such practical problems as how best to eat "hasty pudding"; and then, in September 1795, set out once more for London to publish his papers there.

Before considering Rumford's public career in London we must return, after this long interval, to his private life. It is not known whether, in all these years, he wrote to his wife. The feelings engendered by the war may have made this almost impossible; but there is evidence that he sent money for her and their daughter and also for his mother, and in 1792, after his wife's death, his correspondence with his friend Baldwin, now a Colonel, had been resumed on a friendly footing. His daughter Sally was by this time 22, and on his return to England arrangements were made through Col. Baldwin for her to join him there. This young lady had many of her father's qualities—an observant eye, a love of display, and a dislike of being crossed or managed. If, as Stevenson says, "to marry is to domesticate the recording angel," what words can be found to describe the result of taking a clear-eyed, grown-up daughter to your heart? Father and daughter had each formed a romantic picture of the other, and she found, instead of the handsome and charming young officer described by her mother, an elderly man "who did not strike one as handsome or very agreeable"; whilst he had to deal, not with the

docile child of his imagination, but with a flesh and blood young woman with views and tastes of her own. Sally's education had been somewhat casual, her world in America was very different from her father's in Europe, and Rumford's efforts to fit her for his circle were not always tactful. Sometimes she was submissive, as when she sat silent at a fashionable concert, though preferring "within herself" an old black fiddler at Concord, but at others she was rebellious, as when she refused to be taught by a hideous, hunch-backed Italian, considered by her father a suitable teacher for his gay young daughter. Still, there were many moments when Rumford ceased to act the heavy father, and then "the playfulness of his character" and "his laughter, quite from the heart, nothing made up about it," won Sally's heart, and even the unwelcome Italian teacher was heralded by the gift of a pet dog.

These delicate domestic difficulties, however, only formed a small part of Rumford's life in England; he was busy, as ever, with his schemes of reform and his scientific activities. The pall of smoke over London haunted him as a danger to health and as a sign of waste, and he designed chimneys for saving fuel and diminishing smoke, and also, with the same object, a hot-air oven known as the "Rumford Roaster," for which there was at the time quite a craze. Rumford believed that, in order to institute reforms successfully, it is necessary to "make benevolence fashionable," and his fondness for aristocratic society certainly helped

to bring this about; but it is only fair to him to say that his aim was always to "relieve and help the common people" and that he "never refused to give his services, whether in palace, poor house, or farmer's cottage."

In 1796 Rumford began publishing his Essays, and in the same year he made generous gifts of £1000 each to the Royal Society in England and to the Academy of Arts and Sciences in America. These sums of money were to be used for medals to be awarded, in Europe and America respectively, every two years for "the most important discovery, or useful improvement, made during the preceding two years, on Heat or on Light." Rumford himself had already been awarded the Copley Medal in 1792 for "Various Papers on the properties and Communication of Heat," and later on, in 1802, the "Rumford Medal," given for the first time, was, by a gracious as well as a just act on the part of the Royal Society, awarded to its founder.

Rumford's stay in England was on this occasion a brief one, for the critical state of affairs in Europe in 1796 led him to decide to return to Bavaria, and in the hot days of late July or early August he and Sally made the difficult journey from London to Munich. Finding the Elector on the point of retiring to Saxony, Rumford took over from him the supreme command and upheld Bavaria's neutrality with such wisdom and skill that neither the French nor the Austrians entered Munich. This action was all the more admirable because Rumford's tastes now lay in other directions; "I hope

soon to be able to put up my sword," he wrote to a friend in October 1796, "and resume the more pleasing occupations of science and philosophic experiment."

He was not, as a matter of fact, released from his public duties in Bavaria for another two years; yet his most important discovery falls within this period and arose out of the very work that seemed to be the rival of his scientific pursuits.

While superintending the boring of cannon in the foundry he had built at Munich, his attention was attracted by the great amount of heat generated during the process of boring, the chips shaved off having "an intensity of heat exceeding that of boiling water"; and it occurred to him that further experiments on these lines might settle the age-long dispute as to "the existence or non-existence of an igneous fluid." The scientists of his day held that heat is an imponderable fluid, caloric, which flows from a body at a higher temperature to one at a lower, much as water flows from a place of higher to a place of lower level. They also spoke of substances having different capacities for heat, using the expression in much the same sense as we do to-day.

Now Lavoisier, it will be remembered, had already established the fact of the conservation of matter, and therefore, Rumford reasoned, if heat is a fluid, it can neither be created nor destroyed; consequently, either the same amount of heat must be present in the hot chips and cannon as in the unbored metal or else heat must have reached the

cannon from outside. Having thus put the case clearly to himself, Rumford proceeded to arrange a series of experiments.

Now, if no heat has reached the cannon from outside, the rise in temperature of the chips must be due to the fact that gun-metal in chips has a smaller capacity for heat than metal in a block. When, however, the capacities for heat of gun-metal in these two states were compared, they were found to be the same. It had seemed, from the first, unlikely that the observed rise of temperature in the process of boring could be accounted for in this way, and now this possible explanation was finally disposed of. To illustrate in a striking manner the inherent improbability of this explanation, Rumford repeated the boring experiment, using a very blunt tool, pressed with a force of 10,000 lbs. against the bottom of a revolving cylinder[1]. In this case, only 837 grains (Troy weight) of metal were detached, while the temperature of the apparatus rose from 60° F. to 130° F. in an hour.

"Is it possible," Rumford asked, "that the very considerable quantity of heat that was produced in this experiment (a quantity which actually raised the temperature of above 111 lbs. of gun-metal at least 70° of Fahrenheit's thermometer and which of course would have been capable of melting six and a half pounds of ice, or of causing near five

[1] To economise material, he used, in this and his later experiments, not the cannon itself but the cylinder of gun-metal which, in casting, is left projecting beyond the muzzle of the gun.

pounds of ice-cold water to boil) could have been furnished by so inconsiderable a quantity of metallic dust, and this merely in consequence of *a change* of its capacity for heat?"

In this experiment the external air had free access to the inside of the cylinder, so, to ascertain whether it could have imparted heat to the apparatus, Rumford excluded it by means of a piston. The result was still the same. It was, however, possible that some heat might have been generated in this second experiment by the friction of the piston in the bore of the cylinder, so the whole apparatus was enclosed in a box containing water and the experiment repeated. This time the result was even more striking than before, for in two and a half hours the water boiled!

"It would be difficult," wrote Rumford, "to describe the surprise and astonishment expressed in the countenances of the bystanders on seeing so large a quantity of cold water heated and actually made to boil without any fire. I acknowledge fairly that it afforded me a degree of childish pleasure which, were I ambitious of the reputation of a *grave philosopher*, I ought most certainly to hide rather than discover."

The heat produced in these experiments was not furnished by the chips nor by the outside air, nor, when the apparatus was under water, by the water, for the water was itself heated and could not be both giving and receiving heat at the same time. Yet, as long as the friction continued, the heat was "given off in a constant stream, in all directions,

without diminution or exhaustion." Whence did it come? If heat is a form of matter, it must have come from the apparatus or from outside. It came from neither. What, then, is heat? Rumford pondered these questions and gave his conclusions in a paper read before the Royal Society in January 1798:

> Anything which any insulated body or system of bodies can continue to furnish without limitation cannot possibly be a *material substance*; and it appears to me to be extremely difficult, if not quite impossible, to form any distinct idea of anything capable of being excited and communicated in the manner the Heat was excited and communicated in these Experiments, except it be MOTION.

Shortly after the publication of this paper, Davy melted two pieces of ice by rubbing them together, and so gave further proof that heat is not matter; but, as this experiment was later than Rumford's, and as, moreover, Davy did not at the time see the significance of his own experiment, it is only just to give Rumford the credit for being the first to realise that heat is a form of energy. The importance of this discovery was not at first seen; but though the Caloric Theory held the field for another half-century, it was really from this moment doomed. Mayer's statement in 1842 of the principle of the conservation of energy and Joule's classic series of experiments, lasting from 1843 to 1878, for finding a numerical value for the mechanical equivalent of heat merely completed the work that Rumford had begun. If this had been his sole achievement, it would have estab-

lished his claim to be remembered in the annals of science.

During the two years in which these experiments were being carried on, Rumford was harassed by continual opposition and criticism of his schemes of public service from "jealous and interested parties," and his health began again to suffer. On this account, the Elector, his friend and supporter throughout, wishing to relieve him of his troubles while retaining his services, appointed him Minister Plenipotentiary from Bavaria to Great Britain, and thither he and Sally returned in September 1798 and established themselves in a villa at Brompton Row, Knightsbridge. Greatly to his chagrin, however, Rumford found that his birth as a British subject was considered a barrier to his being accredited as a foreign minister; but this disappointment had one good result in diverting his energies once more into scientific channels.

Rumford's visit to England in 1795–6 and his contact with the Royal Society had suggested the need of another society, less exclusively academic, which would "bring about a cordial embrace between science and art" and establish "relations of helpful intercourse between philosophers and practical workmen." The general plan for such an institution he embodied in a pamphlet published in London in 1799, and so successful was he in securing the interest and financial support of his friends and the general public that the "Royal Institution" was soon in being. It is interesting to know that Rumford was responsible for the ap-

pointment, in 1801, to the Directorship of the Laboratory of a promising youth who afterwards, as Sir Humphrey Davy, added so much to the fame of the Institution both by his own work and by his discovery of Faraday.

Ever since his daughter joined him, Rumford had maintained a friendly correspondence with Col. Baldwin, and we see from this how his thoughts turned more and more towards America. Time, and the knowledge of his fame in Europe, had softened the feelings of his compatriots towards him, and in 1799 this changed attitude was shown by the offer of the Headship of the Military Academy and the post of Inspector-General of the Artillery of the United States. Rumford refused this on account of his work in connection with the Royal Institution, but he was touched and gratified by this recognition on the part of America. He had hopes of ending his days there in some quiet spot, but, though Sally returned in September 1799, he himself never went back.

The Royal Institution had been launched amidst universal approval, but disagreements soon arose. There is no doubt that Rumford liked to be a dictator and to have his schemes carried out in all their minutest details; there is no doubt also that some of these details were impracticable and that other people had views of their own which seemed to them as valuable as his; at any rate, he ceased in a short time to be closely connected with the Institution, and in September 1801 he went to Paris.

During his stay in England Rumford's feelings had been hurt by Cobbett's satire on his soups as "insipid and flatulent compounds...made of dirt and bones," and unfit for any Englishman, however poor, to eat. In France, however, where *soupe maigre* was already the staple dish, his concoctions had been received more kindly and he was flattered to find his inventions in common use and his name known throughout the country.

In this glow of general appreciation, he met and was charmed by Lavoisier's widow, a woman of about his own age, wealthy, still handsome, and the hostess of one of the most famous *salons* of the day. A warm friendship springing up between these two and ripening into love, they decided to marry; but, unfortunately, long habits of independence had rendered both unadaptable and spoilt what promised to be a happy and successful alliance. Rumford, with a certain lack of generosity and good taste that has been noticed before, spoke afterwards with great bitterness of Madame de Rumford; yet, from contemporary accounts, she seems to have been a devoted and enthusiastic young wife to Lavoisier and a charming hostess to a distinguished group of literary and scientific men. When they married, Rumford joined her in Paris and therefore entered a circle of which she was already the centre, and this fact may have acted unconsciously upon him, used to being himself the central figure, and fed an unreasoning dislike of her *salon*. When things had got to the pitch of his locking the gate on her friends, while she retaliated

by pouring boiling water on his favourite plants, it seemed that a joint establishment was no longer possible, and both breathed more freely when in 1809, after four years of friction and unhappiness, Rumford took an estate at Auteuil, four miles from Paris, and retired thither.

Madame Lavoisier had sent friendly messages and valuable presents to Sally during her engagement to Rumford; but after their marriage she did not press her step-daughter to join them, and it was not until after the separation that Sally once more left America for Europe. At Auteuil she found her father broken in health, no longer surrounded, as at Munich, by those who appreciated him and valued his work, content to interest himself in his house and garden and in scientific pursuits and to receive only occasional visits from scientific friends and Americans in Paris. He and Madame de Rumford visited each other periodically, and Sally found her charming and was puzzled to know why they could not be happy together, but shrewdly guessed that "their disagreement must have arisen from their independence of character and means, being used always to having their own ways." He had a class in the Institute in Paris and brought before them, from time to time, the results of his researches; he also read papers before the Institute and some of these were transmitted to be read before the Royal Society; but he became more and more of a recluse and an eccentric in his private life and, in the summer of 1814, sank, a lonely and broken man, into his grave.

Twenty years earlier, Thomas James Mathias had written the following tribute to Rumford:

> Yet all shall read and all that page approve,
> When public spirit meets with public love.
> Thus late, where poverty with rapine dwelt,
> Rumford's kind genius the Bavarian felt,
> Not by romantic charities beguiled,
> But calm in project, and in mercy mild;
> Where'er his wisdom guided, none withstood,
> Content with peace and practicable good;
> Round him the labourers throng, the nobles wait,
> Friend of the poor and guardian of the State.

May we not take this as a just and fitting epitaph for this practical philanthropist?

NOTE

Unless otherwise stated, quotations in this chapter are taken from *Memoir of Sir Benjamin Thompson, Count Rumford, with notices of his daughter*, by G. E. Ellis.

WILLIAM HERSCHEL AND THE DISCOVERY OF THE PLANET URANUS

The heavens are calling you and wheel around you,
Displaying to you their eternal beauties,
And still your eye is looking on the ground. DANTE.

THE mathematician has received more hard knocks on the score of the coldness and lack of romance of his subject than any other scientist; yet, as Fabre writes, though mathematics do not give us "ideas, those delicate flowers which unfold one knows not how, and are not able to flourish in every soil," they teach us to "present them in a lucid and orderly manner," and they are certainly the dry bones without which music and astronomy would be invertebrate. Seen truly, the order and sequence even in pure mathematics has its own romance, for, to use Fabre's words again, "we start from a brilliantly lighted spot and gradually travel farther and farther into the darkness, which in its turn kindles into radiance as it sheds fresh light for a higher ascent." This sense of the romance of "travelling farther and farther into the darkness" is one great incentive to the astronomer and, in the case of William Herschel (1738–1822), proved strong enough to make him—a musician and the son of a musician—forsake the great world of music for the universe of stars.

Little is known of the Herschel family beyond

the fact that the name is Jewish and that Hans Herschel, the great-grandfather of the astronomer, migrated to Saxony from Moravia early in the seventeenth century on account of his Lutheran opinions. He set up as a brewer in a small town near Dresden, and his second son, Abraham, was "employed in the royal gardens at Dresden, and seems to have been a man of taste and skill in his calling." Abraham's youngest son, Isaac, was passionately fond of music and not at all in love with gardening; fortunately he was able to receive a musical training, and by the time he was 24 he had obtained a place as oboist in the band of the Guards at Hanover. The next year, in 1732, he married Anna Ilse Moritzen, and they had ten children, of whom six lived to grow up—Sophia, Jacob, Frederick William (the astronomer), Alexander, Caroline, and Dietrich. Anna was the "thoroughly domesticated" type of woman, a good wife and mother in providing for the material needs of her family, but with little sympathy for their intellectual and aesthetic interests. Perhaps, unconsciously, she felt it a grievance that all but her eldest daughter had their father's brains and musical talents; certainly she spoilt Sophia and "put upon" Caroline and attributed every family trouble to too much learning, so that neither by heredity nor by personal encouragement does she seem to have contributed much to the greatness of her famous son. Isaac was of a different type and, through his real musical enthusiasm, had a great effect on the careers of his sons, insisting that they

should all have a sound training in the theory and practice of music. His work, however, obliged him to be often away from home, and this absence was specially unfortunate for Caroline, as his wife and eldest son, who was by nature a bit of a bully, allotted to her the position of household drudge. When he returned home finally in 1760, ruined in health by the Seven Years' War, he seems not to have had the energy to make any radical changes, but contented himself with giving his ten-year-old daughter an occasional violin lesson after the serious business of teaching his five-year-old son Dietrich was over.

All the Herschel boys attended the garrison school till they were 14. William was particularly quick and keen at his lessons and fond of philosophical arguments with his father at home; he had also considerable mechanical skill, turned to excellent account in his famous telescopes later, and, by 14, was "a competent performer on the oboe and the viol." He was a general favourite, but unspoilt by his popularity and always ready to notice the plain, silent, little sister whom the others were apt to snub or ignore. She, in return, lavished on this "best and dearest of brothers" a passionate affection which, when she grew up, blossomed into a life of devoted service, without which much of his work could never have been brought to fruition.

When the Hanoverian Guards were ordered to England in 1755, Jacob and William were with their father in the band and were away from home

a whole year. William, then only 17, was the oboist and his pay was slight, but out of it he managed to buy one memento of England, Locke *On the Human Understanding*.

In 1757 the French invaded Hanover and William had some "unpleasant experience of actual warfare." His health was not then very good, and his parents—to use the delicate wording chosen by Caroline to describe the sequel to this campaign—"determined to remove him from the service—a step attended by no small difficulties." Sir Robert Ball's account in *The Story of the Heavens* of William's method of changing his profession, though more blunt, is also more correct, for, "to speak plainly, he deserted, and succeeded in making his escape to England." That this is the true version is proved by the fact that, on Herschel's first visit to George III, his pardon was handed to him by the King himself; it is here mentioned because, seen in its proper proportion, it is an essential part of the picture of the man. Cromwell is said to have insisted on his warts being painted in his portrait and a wise man refuses to have the lines smoothed out in his photograph. In the same way, it is a false tribute to a great man to slur over or deny his weaknesses; his greatness lies, not in being born a super-man, but in living more continuously than most people at his higher levels.

Herschel's "removal" from the army was effected so hastily that even his precious copy of Locke was omitted from the parcels sent after him by his

mother, who, "dear woman, knew no other wants than good linen and clothing." He arrived, therefore, in England with nothing but this outfit of clothes and his portable equipment of learning and skill. This last consisted of a "knowledge of French, Latin, and English, some skill in playing the violin, the organ, and the oboe, and an 'uncommon precipitancy' in doing what was to be done."

The most reliable source of information about Herschel's early life is the *Memoir and Correspondence* of Caroline Herschel, compiled by her as an old woman from a journal kept in her youth. In this record there is a significant gap at this period and it is not known with certainty how William spent the next few years. In 1759 he and Jacob were both in England, for in that year Jacob is mentioned as returning home and leaving William behind in England. He lived in various towns in Yorkshire, earning his living by means of his music, and in 1765 he became organist at the Halifax Parish Church. This post he held for only a year, as in 1766 "he obtained an advantageous engagement as oboist at Bath" and shortly afterwards was appointed organist at the Octagon Chapel.

Bath was at that time "a rendez-vous of the diseased," where "ministers of state, judges, generals, bishops, projectors, philosophers, wits, poets, players, fiddlers, and buffoons" met and trifled amid "dressing, and fiddling, and dancing, and gadding, and courting, and plotting"; and Herschel was at first merely one of a band of entertainers and quite

unknown to this gay world of fashion, to whose pleasure he helped to contribute. When he came to Bath the musical director there was Linley, and his daughter Elizabeth, called "the Siren" for her "taste and execution" in singing, was taking the leading soprano parts in the concerts. She had, however, many suitors and eventually selected Richard Sheridan from among them; they were married in 1773. Before that date she had given up her public engagements, and this gave William Herschel the opportunity of suggesting that Caroline should join him, in the hopes that she could be trained to succeed Miss Linley.

This offer was prompted partly by the desire for professional and financial success, but even more by the wish to rescue his sister from her life of drudgery at home. The father's health had failed steadily since the Seven Years' War; in 1764, at the time of a brief visit from William, he was an invalid, and in 1767 he had died. With the exception of William, he had been kinder to Caroline than any other member of the family and she was staggered by his death. "She was plain in face and small in stature, and her father had often warned her that if she ever married it would be comparatively late in life, when her fine character had unfolded its attractions." Meanwhile what could she do? From earliest childhood she had been trained only in house-work, plain sewing, and knitting; at six she was being scolded by Jacob for her clumsiness as a waitress, and the first stocking she knitted for one of her brothers "touched the ground while

she stood upright finishing the toe." The result of this upbringing was that at seventeen she "was qualified, as she reflected with anguish, only to be a housemaid." If she could learn fancy-work, she thought that, perhaps, with this accomplishment and "a little notion of music, she might obtain a place as governess in some family where the want of a knowledge of French would be no objection." With this end in view she contrived, unknown to her mother and in spite of heavy household duties, to get some lessons from a consumptive girl, "whose cough gave the signal for a daybreak rendez-vous," and after a time she was actually allowed to have some lessons in dress-making and millinery. William's offer, however, completely changed the direction of her ambitions; but, even now, all was not plain sailing. Jacob, after a brilliant but brief and unsuccessful career at Bath, had returned home in no mood to help Caroline, as William had suggested, by giving her singing lessons. Without even testing her voice, he "turned the whole scheme to ridicule," so that she was left for months in "harassing uncertainty" as to whether or no she was to go. At last she decided to prepare for either alternative, first, by trying when she was alone in the house to imitate with a gag between her teeth "the solo parts of concertos, *shake and all*," and secondly, by redoubling her knitting activities, making, poor girl, enough cotton stockings to last her mother and Dietrich for two years at least and some ruffles which, if she stayed, were to be William's, or, if she went, Jacob's. This unsatis-

factory state of affairs was fortunately brought to an end by the arrival, in August 1772, of William himself. He promptly offered to pay his mother for a servant in place of her daughter, who indeed "felt herself to be her mother's slave, to be bought and sold," and returned with Caroline to England.

The season at Bath began in October, so that the next few weeks were fully occupied in training Caroline's voice, which luckily proved equal to William's expectations and enabled her eventually to take the leading soprano parts in the winter concerts at Bath and Bristol. Her pleasure at her success and at fulfilling her brother's hopes was, however, to a great extent damped by his increasing absorption in astronomy and the consequent demands made upon her. It is rather pathetic to read that, at the time he shot meteor-like into fame, she was "left alone to amuse herself with her own thoughts, which were anything but cheerful," since she discovered that she "was to be trained for an assistant astronomer" and that all hopes of realising her ambition of gaining a "creditable livelihood" as a singer must be abandoned. She found she had exchanged one form of servitude for another; but William, though an exacting, was never a contemptuous task-master, and her love for him carried her, with only occasional bouts of grumbling, through the difficult years of self-effacement and out at last into the joy of service and of discovery shared with him.

Isaac Herschel had been "a great admirer of astronomy, and had some knowledge of that sci-

ence," so that William as a boy had had his interest in the subject aroused. His study of the theory of music involved the learning of mathematics, and this made easy the further step to optics, and so, by way of the telescope, to astronomy. It was, however, his first view of the night-sky through a "small and imperfect telescope" which, as Sir Robert Ball tells us in *The Story of the Heavens*, "changed the whole current of his life." "The stars he had seen before he now saw far more distinctly; but, more than this, he found that myriads of others previously invisible were now revealed to him," and he was fired with the desire to look "further into space than ever human being did before him."

To realise this ambition, he hired a small reflector; but this was of little use, and he was evidently in search of a better instrument at the time that he brought Caroline to England, for, on their arrival in London, "when the shops were lighted up, they went to see all that was to be seen, of which she only remembered the opticians' shops, for she did not think they looked at any others."

The price of a good instrument proving quite beyond his means, he made the momentous decision in the winter of 1772 to be his own optician. Alexander, a much pleasanter member of the family than Jacob and, like him, an accomplished musician, had been for some time with William, playing the violin at the concerts during the Bath season. He shared William's mechanical skill but not his hopeful nature, so that his brother and

sister called him "Dick Doleful" and had often to laugh him out of his fits of the blues. In a workshop, however, he was perfectly happy, and in the June of 1773, "when fine folk had mostly deserted Bath for summer resorts," the two brothers set to work "with boyish glee" on William's ambitious scheme. Caroline, brought up in a tidy German home, saw with dismay the drawing-room turned into a carpenter's shop and Alexander enjoying himself fitting up a huge lathe in the best bedroom. In spite of her misgivings, however, she was always ready to help and "became in time as useful a member of the workshop as a boy might be to his master in the first year of his apprenticeship." Besides her odd jobs as laboratory assistant and errand-boy, she had her domestic duties and was continually having to adapt the household arrangements to suit her brothers' needs. "Even at meal-times William was generally employed 'contriving or making drawings of whatever came in his mind,'" and tea and supper were eaten while he worked.

Most of the instruments made or attempted by Herschel were reflecting or Newtonian telescopes. In this type the rays from the star fall on a concave mirror, whose axis is slightly inclined to the path of the rays, so that they are brought to a focus to one side of the incident beam and there viewed through an eye-piece in the usual way. The success of this instrument depends mainly on the perfection of shape and surface of the concave mirror or "reflector." Herschel's method of working was to

FREDERICK WILLIAM HERSCHEL

cast and finish a number of mirrors, then to test them and to repolish the least perfect. The finishing was particularly tedious, as it had all to be done by hand, and the shape of the metal might be spoilt if the hands were removed even for a moment. During this process Caroline "sustained her brother physically and mentally, putting food into his mouth, and reading aloud *Don Quixote* and the *Arabian Nights*," and, on one occasion, his hands never left the mirror he was polishing for 16 hours.

In the midst of this engrossing work, preparations for the winter season had to go on as usual; Caroline, besides music-lessons, had to fit in two hours a week with a famous dancing-mistress, whose task was "to drill her for a gentlewoman," and all three had to practise regularly and attend numerous rehearsals. When the season came, there was, of course, less time than ever for astronomy; yet in 1775, *between the acts at the theatre*, Herschel made a review of "every star in the sky of the first, second, third, and fourth magnitudes, and of all planets visible."

Before 1775, as a matter of fact, Herschel had produced a tolerably successful telescope, of five-and-a-half feet focal length, and through it had observed, in March 1774, the nebula of Orion. This first success sounds insignificant, but two hundred mirrors had been made or attempted before even this result was achieved, and the labour expended and the skill acquired in producing these "two hundred failures" made possible the production of his magnificent 20-foot and 40-foot instruments.

Herschel's review of the heavens in 1775 had mainly impressed him as showing up the inadequacy of his instruments; from that date till 1781 he was gradually perfecting the parts and increasing the lengths of his telescopes, and by 1781 he had made "not less than two hundred 7-foot, one hundred and fifty 10-foot, and about eighty 20-foot mirrors." During this period, and in spite of the fact that "he used frequently to run from the harpsichord to look at the stars" in the intervals at the theatre, he managed to make a success of the musical directorship, which he had taken over from Linley in 1776. "From conducting a brilliant concert at Bath, when that city was at the height of its fame," writes Sir Robert Ball, "Herschel would rush home, and, without even delaying to take off his lace ruffles, he would plunge into his manual labours of grinding specula" (another name for reflectors) "and polishing lenses."

In 1780 Herschel began a second review of the heavens with a 7-foot Newtonian telescope, which, as he truly said, was "for distinctness of vision equal to any that was ever made." With this instrument he saw, on March 13th, 1781, in the constellation of Gemini, an object which "had a minute, but still a perfectly recognisable, disc." Other observers had seen this object before, but, with their inferior instruments, it had appeared a mere point. The significance of the difference lies in the fact that, the more perfect the telescope, the smaller is the image of a star, but the larger the image of a planet or comet. Now, "at that epoch,"

as Miss Clerke writes in *The Herschels and Modern Astronomy*, "new planets had not yet begun to be found by the dozen. Five, besides the earth, had been known from the remotest antiquity. Five, and no more, seemed to have a prescriptive right to exist. The boundaries of the solar system were of immemorial establishment. It was scarcely conceivable that they should need to be enlarged." Herschel's modesty at first prevented him from making the tremendous claim that his discovery was a new planet, and so, although he had noticed that it "moved in planetary fashion from west to east, and very near the ecliptic," he described it as a comet in the account he sent to the Royal Society. Even so, he was elected, on the strength of this communication, a Fellow of the Royal Society in December 1781, was formally "admitted" in May 1782, and was awarded the 1781 Copley Medal for "his discovery of a new and singular star."

Meanwhile there was a flutter in all the observatories of Europe and the official astronomers set to work to observe and identify this "singular star" of Herschel's. The English astronomers inclined, almost from the first, to the view that it was a planet, the French to the notion that it was a comet. This friendly difference of opinion, however, was ended by Lexell of St Petersburg, who proved it to be a planet, about nineteen times as far as the earth from the sun; and in due time it received its present name of Uranus.

Here was a new sensation for the fashionable

idlers of Bath! Herschel, the great astronomer? Of course they knew him. Had they not patronised his concerts and found pupils for him? To be in the fashion they had only to get a talk with him and a peep at his wonderful telescope. After the discovery of Uranus "few men of learning or consequence left Bath before they had seen and conversed with" Herschel, and his important work was thereby considerably hampered.

This sudden fame interrupted Herschel, but never deflected him from his passion for studying "the construction of the heavens" or his determination to improve and enlarge his instruments still further for this purpose. After many trials, he successfully erected a stand for a 20-foot telescope in his garden and, in the unusually busy winter of 1781–2, he made plans for casting a 30-foot reflector. For this a special furnace had to be built and his pupils began to suffer, for, "if a minute could but be spared in going from one scholar to another, or giving one the slip, he called at home to see how the men went on with the furnace." Needless to say, he and Alexander talked of nothing else, and Caroline sat up with William through many "a long night's watching," keeping his fire up, making him cups of hot coffee, and lending him a helping hand in his work. As soon as the concert season was over, a day was fixed for casting the metal in the mould of pounded and sifted loam prepared for it. Unfortunately, before the molten metal could be poured out, the vessel containing it began to leak, and only a speedy retreat from the

furnace-room prevented the premature close of the famous astronomer's career, for the stone floor flew ceiling-high in all directions.

Before a second casting could be attempted, however, an event occurred which changed the whole course of the Herschels' lives. The King had by this time heard of the discoverer of the new planet and sent a royal command that he should come to Court, bringing his telescope with him. In May 1782 William therefore made the journey to London. The King was much interested in Herschel himself and in what he had to say; the telescope was set up at Windsor and His Majesty saw, with wonder, Saturn and his rings and other astronomical sights. The ladies of the Court next demanded a view of these fascinating objects, but, alas, the night chosen for their show was overcast. Herschel, however, had not observed the signs of the weather for nothing, so that, foreseeing this possibility, he had provided against it beforehand and delighted the royal ladies with an excellent sham Saturn, made by cutting a hole in a piece of cardboard, placing it against a distant garden wall, and illuminating it from behind! The King and Court were so much impressed by Herschel and his telescope that he was kept in London some weeks, during which time Caroline had to deal as best she could with clamouring pupils at Bath; and finally the King decided that he could not part with Herschel at all and offered to make him royal astronomer at the princely salary of £200 a year. Herschel was thankful to accept any terms in ex-

change for freedom from the irksome task of teaching music, but Caroline, as we have already seen, regarded the proposed abandonment of their musical careers with dismay; and Sir William Watson, the only friend to whom Herschel confided the amount of the King's provision for him, indignantly exclaimed "Never bought monarch honour so cheap!" Nevertheless, from the point of view of Herschel and of astronomy, it was a wise decision, for during the remaining 40 years of his life he was free to devote himself to his telescopes and stars. The musical careers of William and Caroline Herschel closed with the service on Whit-Sunday, 1782, in St Margaret's Chapel, Bath, the anthem being William's own composition, and by August 1st they were established at Datchet in their new roles of royal and assistant astronomer.

From Caroline's point of view the new home, dilapidated and isolated, had nothing to recommend it, but from William's it was ideal. It possessed a laundry that would do for a library, a large stable cut out to be a workshop, and a small lawn large enough to hold a 20-foot telescope. The family budget was another source of anxiety to Caroline, since, as Miss Clerke puts it, "the opulence of Bath had been exchanged for the penury of a court precinct," and the problem was hardly solved by William's cheerful masculine offer to live on eggs and bacon; but they set to work in good earnest, he at the congenial task of "minding the heavens" and she at "minding the heavens and the earth too." William continued making

telescopes and reviewing all stars above a certain degree of brightness, and Caroline, who proved an apt pupil, helped him when necessary and was also allowed to "sweep for comets" on her own account. She soon became expert at this sweeping and interested in it, and in 1786, when William's absence from home left her free for her own work, she discovered her first comet—the first ever discovered by a woman—and, in the course of her observations, found in all eight. She never considered her scientific reputation except as an adjunct to her brother's and was "more shocked than gratified" when her cataloguing of some of his work, as an old lady of 75, won her the Gold Medal of the Royal Astronomical Society. Her achievements are not of course comparable with his, but she must have possessed considerable ability to do what she did under the conditions of her life.

In June 1785 the Herschels moved to Clay Hall, Old Windsor, and in April 1786 made their last change to Slough. William's enthusiasm for astronomy can be judged by the fact that "the last night at Clay Hall was spent in sweeping till daylight, and by the next evening the telescope stood ready for observation at Slough." Their financial position continued precarious, but Sir William Watson's views on the subject filtered through, in due time, to the Court and produced a grant of £2000 for a 40-foot telescope, which enabled Herschel to carry on this expensive piece of work. He continued to make telescopes of all

sizes and the sale of these eventually brought in a comfortable income.

In May 1788 William Herschel married "Mary, only child of Mr James Baldwin, a merchant in the city of London, and widow of Mr John Pitt." He was 50 and she 38 at the time of their marriage, and, four years later, their only child was born—John, who became himself a famous astronomer.

Caroline, on her brother's marriage, ceased to be his housekeeper but continued to be his astronomical assistant. As was only natural, she had a struggle with her jealousy of her sister-in-law, but in time grew fond of her, and John was from the first her nephew *par excellence.* In the family circle and among their friends she retained the position which her character and scientific work had made for her.

Herschel's wife was a woman of ample means, but, although her jointure did relieve him of financial anxieties for the rest of his life, there is no reason to think that he married her only for her money. All visitors to Slough agree that the family party, with the quiet, gentle wife, the bright little boy, the interesting sister, and the unassuming, pleasant-mannered, astronomer himself, gave the impression of a singularly happy home.

This busy and peaceful life went on without interruption save for the sometimes inopportune visits from members of the Court, whom the terms of Herschel's appointment as King's Astronomer obliged him to receive. Caroline from the first saw that this duty of acting as "showman of the

heavens" would tax his strength by making demands on him when he might happen to be tired out after a succession of all-night vigils, but she could not always find a suitable pretext for getting rid of unseasonable visitors. William must have been a strong man to stand the outdoor night-work to which he constantly exposed himself, but at last even he overstepped the limits of his powers of endurance. In October 1806 the appearance of a bright comet drew such a stream of sight-seers from the Court to Slough that Herschel had not "during the whole month...an evening to himself." He was at the time engaged in the exhausting work of polishing the 40-foot mirror, and Caroline gives it as her opinion that "on the 14th of October his nerves received a shock from which he never got the better afterwards; for on that day he had hardly dismissed his troop of men (helpers in the polishing) when visitors assembled, and from the time it was dark, till past midnight, he was on the grass-plot surrounded by between fifty and sixty persons, without having had time to put on proper clothing, or for the least nourishment to pass his lips."

The sequel was a serious illness in the spring of 1807, and, though he recovered from this, the record of the rest of his life is, in the main, the sad one—sadder perhaps for the watchers than for himself—of failing strength and powers and spirits; and at last, in 1822, the worn-out body was laid to rest. On his grave in the church of St Lawrence at Upton are carved the words *Coelorum perrupit*

claustra—"he broke through the barriers of the skies." This fitly describes his life-work and leaves the horizon undefined, so that to many it will seem to mean also that, in death, his gallant spirit pierced the overhanging darkness to some land of starry brightness beyond.

Books of Reference

Sir William Herschel, His Life and Works, by E. S. Holden.
William Herschel and His Work, by J. Sime.
The Herschels and Modern Astronomy, by A. M. Clerke.
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FABRE, POET OF SCIENCE

Man's work is his soul. IBSEN.

LEGROS, by a happy inspiration, begins his life of Jean Henri Fabre with an idea taken from Emerson that everything in creation has its appointed painter or poet and remains in bondage, like the princess in the fairy-tale, till its appropriate liberator comes to set it free. The story of the Sleeping Beauty is something more than a fairy-tale; it is an allegory of the life of every human being who fights his way through the thickets of his own particular "dark forest" to the beauty that lies at its heart, waiting for his wakening touch. This parable is peculiarly applicable to Fabre, for he was one of those rare people with the mind of a scientist and the heart of a poet, and his claim to greatness lies not in any one dramatic discovery nor in any specially illuminating theory, but in the fact that he breathed life into a lifeless subject.

Jean Henri Casimir Fabre (1823–1915) was the son of Antoine Fabre and his wife, Elisabeth, and was born at Saint-Léons, the market-town of the canton of Vézins, in the south of France. The Fabres were a humble, unenterprising race, cultivating their own small piece of land or working as labourers for others. There is no trace of scientific curiosity on either side of Henri's family; there was no time for that. "What difference did it make to us whether the earth was round or square?"

he wrote; "in either case, it was just as hard to make it bring forth anything."

When Henri was quite small, the pinch of poverty led to his being sent to his grandparents at Malaval, "to relieve the poor household of one mouth," and here, in his solitary life "amidst the geese, the calves and the sheep," his mind first woke to consciousness. To this awakening Jean-Pierre and Elisabeth Fabre can hardly be said to have directly contributed; "they had never opened a book in their lives," and they "kept a lean farm on the cold granite ridge of the Rouergue table-land," from which incessant toil wrested a meagre livelihood. The old grandfather was versed only "in the lore of cows and sheep," and Henri shrewdly guessed that, had he known that his young grandson was more interested in grasshoppers and dung-beetles than in the solid realities of farming, he would have tried the effect of a good smack on the head as a recipe for knocking such nonsense out of it.

At the age of 7 Henri returned to Saint-Léons to attend the local school, kept by his godfather, Pierre Ricard. The room where the children were taught "was at once a school, a kitchen, a bedroom, a dining-room, and, at times, a chicken-house and a piggery." The schoolmaster, an excellent man with the makings of a successful teacher, was, besides, a bailiff for an absentee landlord, a barber, a bell-ringer, and a choir-singer. What wonder if the schooling, under these conditions, was somewhat informal and interrupted?

To Henri and each of the smaller boys was given "a little penny book, the alphabet," with a pigeon on the cover, but as the master's time was fully occupied with the older boys, the contents of the book remained a mystery and Henri got nothing from it but a friendly feeling for his pigeon, which recalled pleasant out-door scenes of "beeches, raising their smooth trunks above a mossy carpet studded with white mushrooms that look like eggs dropped by some vagrant hen" or of "snow-clad peaks where the birds leave the starry print of their red feet."

Apart from lessons, there was plenty to keep the children interested in the schoolroom. The fire, more even than usual, was the "red heart" of the chilly room, and in winter each boy must bring his own log to help to keep it blazing, not only to warm the school but to keep boiling three pots of pigs' food, always simmering over it. The bolder spirits among the boys would spear a well-cooked potato when the master's back was turned and add the hot morsel to the nuts and crusts nibbled freely by timid and bold alike. Another diversion was caused by leaving the door ajar so that the litter of piglets scratching about outside would come filing in, attracted by the savoury smell, and would trot round grunting and curling their tails, to be followed by the hen and her pretty chicks, pecking here and there for the scattered crumbs.

In summer every boy who was old enough to work in the fields did so, and school for the survivors would then resemble Mr Squeers' famous

establishment in its absence of formal book-learning, lessons being frequently set aside for some practical occupation, such as getting in the master's crops, cleaning out the pigeon-houses, or killing snails in the box-borders of the old castle, for which he was responsible. For Henri Fabre these were field-days in more senses than one; he made the acquaintance of frogs and locusts and of the brilliant blue Hoplia beetle, while on the snail-hunts he followed the example of Saul when he spared the Amalekites, by surreptitiously pocketing the snails with their pretty shells instead of obeying the order that they should be utterly destroyed!

Perhaps, however, the day of greatest enchantment in his boyhood was the one on which he was deputed to take the family ducklings to a lonely stream on the hill-side above their cottage. There, while "the ducklings clapped their beaks and rummaged here, there, and everywhere," Henri filled his pockets with glorious finds—sparkling crystals that must be the precious gems of the fairy tales, sand gleaming with gold that will make the poor family rich for life, something like a ram's horn turned to stone, and, shut cosily into a snail-shell by a leaf, a little beetle of such "an unutterable blue" that "the angels in paradise must wear dresses of that colour." Any of us who have made similar discoveries can guess the sequel, the eager walk home and the withering reception—a hearty scolding for torn pockets and the wondrous treasures consigned to the rubbish-heap. Yet, for all the pain of disappointment, Fabre would not have

missed that "pond aflower with illusions," for "those ponds do not occur twice in a life-time. For luck like that, you must be in all the glory of your first breeches and your first ideas."

In 1833, when Henri was 10, Antoine Fabre took the step, unprecedented in the annals of his family, of leaving his native village for the town of Rodez. There he kept a café, and Henri was able to attend the *lycée* free of charge in exchange for services in the chapel. Although out-door pursuits and the study of nature remained his master-passion and the Thursday half-holiday was the red-letter day of the week, he worked hard at his school subjects and, as time went on, became interested in Latin and learnt to love his Virgil for the "exquisite details concerning the Bee, the Cicada, the Turtle-dove, the Crow, the Nanny-goat, and the golden broom."

After four years at Rodez the family had to move to Toulouse, where the father again kept a café and Henri was able to attend a priests' school free. Ill-luck, however, dogged their footsteps, and, another move to Montpellier a year later bringing no improvement in their fortunes, Henri was at last obliged to take to the road and fend for himself. Legros in his *Life of Fabre* draws a pathetic picture of this waif of 15 on the great white roads, earning with the sweat of his brow a precarious livelihood, one day selling lemons at a fair or in the market-places, and another joining a gang of labourers working on a new line from Beaucaire to Nîmes. He must have known some grey and lonely

hours, but through it all his love of nature and of learning sustained him so that he would forget his troubles in some insect find, such as the glorious Cockchafer of the Pines, or feed his mind at the expense of his body, as when he spent his last *sou* on a slender volume of the poems of Reboul, the workman poet. Most people are primarily interested either in people or in things; Fabre, even at this age, had the unusual power of intense affection for both, and combined a love of study and a passion for truth with the highest of all gifts, that of feeling deeply and understanding truly. Even in want and misfortune can we dare to pity such a rare and gallant soul?

At Avignon the ex-hawker of lemons plucked up his courage, sat for the examination for a bursary at the "Ecole Normale," and sailed in an easy first. This marked a turn in his fortunes; he spent three years at the College and grew to love it, in spite of its dismal, sunless rooms, opening "like bears' cages" off a central court-yard. His hard work at the *lycée* at Rodez had not been wasted and the classical lessons at the Normal College were child's play to him, so that, while around him future schoolmasters were puzzling over their Latin, he had many spare moments for examining "in the secrecy of his desk, the fruit of the oleander, the flower of the snap-dragon, the sting of a wasp, the wing-cover of a gardener-beetle."

The science taught in the Normal College consisted "mainly of arithmetic and odds and ends of geometry...a word or two about a red moon, a

white frost, dew, snow, and wind," and such scraps of "rustic physics"; but once, in a burst of enthusiasm, the science master offered to provide a "feast of learning" by preparing oxygen. It was the last day of term and the class flocked in in gala attire and pressed, with offers of help, round the master as he filled a retort with manganese dioxide and strong sulphuric acid and set it over a coal stove. The only scientist in the room, Fabre, distrusting these "familiarities with the unknown," hung cautiously aloof and so was ready, when the retort exploded, scattering boiling vitriol in all directions, to render first aid to the hapless victims and their ruined Sunday suits!

About 1843, before he was 20, Henri found himself a full-fledged teacher, in charge—at the princely salary of 700 francs (about £28) a year—of the primary school attached to the College at Carpentras. The school-room was a "sort of huge cellar oozing with damp" and lighted only by "a narrow prison-window, with iron bars," and the school properties consisted of a plank bench, fastened all round the room, a seatless chair, and a black-board and some chalk. Under these conditions Fabre was supposed to keep profitably employed "some fifty young imps," of different ages but alike in their determination to play tricks on the new master. "My one resource," he writes, "was my tongue, my one weapon my stick of chalk," and with these he skilfully kept his opponents in the unequal contest from getting through his guard. After a year, however, things improved; the ap-

pearance of tables eliminated the informal scribbling on knees, and, better still, the arrival of an assistant master enabled Fabre to create a preparatory division of younger boys and real duffers and so to keep a more homogeneous class of older and brighter boys for himself.

There were some advantages in those days of hap-hazard education, and one of the chief was that the master could choose his own curriculum. Now that Fabre had his "upper primary" school, he determined to teach them chemistry—the composition of the soil and the diet of plants for the future agriculturalists, important facts about "pickling, soap-making, stills, tannin, and metals" for the future town workers—and, finally, to show them the preparation of oxygen.

When the apparatus for this bold experiment had with difficulty been collected, Fabre, remembering the disaster of Avignon, purposely exaggerated the danger, so that the class sat breathless in their places while he and his chosen "lab.-boy" alone stood near the retort. Soon the bubbles came "gloo-glooing" through the water in the bell-jar, and when the glowing wick of a candle burst into vivid flame in the gas collected, Fabre was inwardly as astounded at his success as his audience was at the relighted candle. The steel ribbon, too, burnt according to programme, forming a "splendid firework," from which a red drop fell at intervals and shot hissing through the water below. "This metallic tear," Fabre expressively says, "with its indomitable heat, makes every one

of us shudder. They stamp and cheer and applaud. The timid ones place their hands before their faces and dare not look except through their fingers. My audience exults; and I myself triumph. Ha, my friends, isn't it grand, this chemistry!"

This was a red-letter day in Fabre's life, and this lesson was the forerunner of a successful course on the preparation and properties of hydrogen and of the principal non-metals. The fame of the school was noised abroad and the numbers grew. "Some more places were laid in the dining-hall," Fabre humorously says, "and the Principal, who was more interested in the profits on his beans and bacon than in chemistry, congratulated me on this accession of boarders."

Another original feature in the school time-table was out-door geometry and surveying, and this deserves mention on account of an interesting discovery that arose out of it. Laden with stakes, arrows, and a precious five-franc graphometer, Fabre and the class would set out for a neighbouring *harmas*, or untilled flinty plain; but, arrived there, the boys behaved in an unexpected manner. One, sent to plant a stake, would stop frequently and stoop down; another, despatched to find an arrow, would pick up a pebble instead; a third, supposed to be measuring an angle, would be seen crumbling a clod of earth; while almost all would be found licking bits of straw. Fabre, instead of merely dealing with the inattention to work as many schoolmasters would have done, enquired into its cause and discovered that the boys knew,

what he did not, that there is a big black bee that makes clay nests in the *harmas* from which strong-flavoured but pleasant honey can be sucked up through a straw. Fabre abandoned his surveying for the time being and joined the nest-hunters, and he became so fascinated with this wonderful bee that he repeated his boyish recklessness by spending money, literally needed for his daily bread, on a magnificent book on insects called *Histoire naturelle des animaux articulés*.

This book was a revelation to him. "In it," he writes, "I learnt the name of my black bee; I read for the first time various details of the habits of insects; I found, surrounded in my eyes with a sort of halo, the revered names of Réaumur, Huber, and Léon Dufour; and, while I turned over the pages for the hundredth time, a voice within me seemed to whisper 'You also shall be of their company!'"

Although Fabre's tastes would have led him to give every spare hour to the study of nature, he realised that the best thing for him to do next was to improve his worldly position and his earnings; and he therefore determined to teach himself mathematics and science with a view to qualifying as a secondary teacher. This resolve crystallised into action in an unexpected way. We all know, and have perhaps been annoyed by, a certain type of person who, hearing that we have shown proficiency in one subject, takes for granted that we are wells of learning in all. One of these people—a youth of about Fabre's own age—arrived one

day and demanded to be taught algebra for some civil engineering examination. Now the arithmetic at the Normal College had not extended beyond square root; the logarithm tables had been as much a sealed book to Fabre as the "pigeon-book" of his childhood; and of algebra he had no knowledge at all. Most of us would have refused at once, but Fabre, almost without a pause, answered "Very well, come the day after to-morrow at five, and we'll begin."

Here he reminds one vividly of the fairy prince, furnished with an impossible task and a time-limit; he had given himself the "blessed Thursday" half-holiday, and that was all. How was he to get an algebra book in time to "cook up" the first lesson? Now Fabre and most of the masters lived in the College, but the science master, though he had rooms in the building, lived in the town; and so, on the half-holiday, Fabre was able to borrow an algebra book from his rooms in his absence and thus avoid the ridicule which his rash scheme would have called forth if it had been discovered. This done, he opened the book at random, like those seeking for a sign in the Bible, and lighted on Newton's Binomial Theorem, and, finding to his amazement that he could understand it, he began his course of algebra with this subject! It is a sign of both his genius and his perseverance that, from this unusual starting-point, he led his pupil safely through the mazes of algebra in the appointed time, and also taught himself with such success that, when he had brought his other sub-

jects up to the required level also, he was able to pass the examination for the degree of licentiate in mathematical sciences.

This success led to his appointment as Professor of Physics and Chemistry in the *lycée* at Ajaccio in Corsica, a post which carried with it a salary of 1800 francs, a beggarly £72, but wealth as compared with the £28 he had earned as a primary teacher. Fortunately his work for the school was light and he had leisure to continue his study of mathematics and his observations of nature. The glorious country and the sea called him and he plunged deep into their wonders. A great botanical collector, Requien, came to Ajaccio, and from him Fabre got light and inspiration; while a visit the next year from Moquin-Tandon, a famous botanist who was a philosopher and poet also, proved a turning-point in Fabre's life.

"Leave your mathematics," said Moquin-Tandon, "no one will take the least interest in your formulae. Get to the beast, the plant; and if, as I believe, the fever burns in your veins, you will find men to listen to you."

They were on the slopes of Monte Renoso, finding, under Fabre's guidance, such rare botanical specimens as the hoary everlasting and the many-headed thrift. When Fabre heard these words of enthusiastic faith, however, he was too overwhelmed by them to attend any longer even to the hoary everlasting. He pondered deeply on his friend's advice, and when he came down from the "cold mountain-top," he had decided to risk all

and abandon his useful mathematics for the apparently useless but absorbing study of nature.

Before leaving, Moquin-Tandon gave Fabre another piece of valuable advice and help. "You interest yourself in shells. That is something, but it is not enough. You must look into the animal itself. I will show you how it's done." Then, "taking a sharp pair of scissors from the family work-basket and a couple of needles stuck into a vine-shoot," by way of dissecting needles, he spread the organs of a snail before Fabre, explaining them by the aid of sketches, and so gave him the first and last natural history lesson of his life.

In 1852 an attack of malaria decided Fabre to apply for work on the mainland, and, curiously enough, he was appointed professor of Physics and Chemistry at the *lycée* at Avignon. As the schoolmaster of 28 looked back on the penniless boy of 15 knocking at the door of the Normal College, he had cause for pride as well as thankfulness for the progress he had made towards his goal; yet there was never a trace of the arrogance so often shown by self-made men. "His youth, his enthusiasm, his good humour, the simplicity of his manners, and the vivacity of his mind," writes one of his biographers, "naturally endeared him to young people eager for knowledge and the ideal," and, with these gifts, it is not surprising that his relations with his class of five or six pupils at the *lycée* were peculiarly happy and friendly.

His success and happiness in his school-work, however, did not deflect him from the decision

taken on the cold mountain-top of Monte Renoso, and every spare minute was now devoted to the study of plants and animals. On whole-school days in term-time he would snatch hours in the morning or evening to cross the Rhône and climb the cliff beyond, to the barren table-land of Les Angles; and on Thursday afternoons and in the holidays he would go further afield, very often to the spot misnamed the Bois des Issarts. This was no cool shady wood, but a coppice of sparsely-growing holm-oaks on a plain so burning in summer that Fabre had sometimes, when he had forgotten his large umbrella, to put his head down a rabbit-hole to avoid sun-stroke! Here, in the dry heat, the insects thronged and revelled, and many strange companions shared with him the shade of the large umbrella for the afternoon siesta. Gad-flies of all kinds would settle on the tightly-stretched cover, and one afternoon, as he was lazily watching their "great gold eyes" and their "solemn progress" from a hot to a cooler spot, he was startled by a sharp "ping" followed by a succession of "pings," as if a mischievous urchin were throwing pebbles at the umbrella. Looking up, however, he saw that the attack was directed not at himself but at the gad-flies, each "ping" representing the bang of a Bembex, or Hunting Wasp, as she darted up to the "silken ceiling," to retire in a moment, after a brief struggle, "with a victim between her legs."

At this time plants as well as animals claimed some of Fabre's attention; but an illuminating monograph by Léon Dufour, the wonderful old

entomologist, concentrated his observations on insects, and shortly afterwards he published an article supplementing Dufour's and was awarded a prize for it by the Institute of France.

It is interesting to know that, while Fabre was at Avignon, Pasteur, who was travelling in the district in connection with his researches into the silk-worm disease, paid him a visit. The pet scientific craze of the day was "spontaneous generation," and Fabre had been delighted to hear that Pasteur had exploded it by a rigorous series of experiments and was therefore ready with a warm welcome. Remembering Pasteur's complete triumph over the silk-worm disease, it is amusing to discover, on reading an account of this interview, that he started his researches as ill-equipped as Fabre had been for his algebra lessons, for till this occasion he had never seen a cocoon nor known what it contained!

Meanwhile Fabre's name was beginning to be known outside scientific circles. At a school inspection he had been much taken by the personality and "impassioned zeal" of one of the literature inspectors, Victor Duruy, and this attraction seems to have been mutual, for, two years later, M. Duruy, now Minister of Public Instruction, came to visit him in his laboratory. Fabre happened to be in his shirt-sleeves, experimenting with printing in madder-red, and his hands were "the colour of boiled lobster-claws." Caught literally red-handed at his work, Fabre retained his wits and his humour, and when pressed to name his wants for the laboratory, demanded the hide of a crocodile from the

Paris "Jardin des Plantes," saying he would stuff it and hang it from the ceiling so that his workshop might "rival the wizard's den"!

This independent spirit, so different from the usual "official bowing and scraping," pleased the Minister so much that, six months later, he sent for Fabre. Fabre, however, fearing an offer of promotion to a more important school, wrote begging to be left "among his vats and his insects," only to receive the reply, "Come at once, or I shall send my gendarmes to fetch you."

On his arrival in Paris, M. Duruy welcomed him with "exquisite cordiality," showed him his name in the list of the Legion of Honour, and himself gave him the accolade, saying "You will like the ceremony all the better if it is held in private, between you and me; I know you!"

Besides this honour, the Minister gave him a parcel of scientific books and a roll of 1200 francs to pay for his enforced journey, and insisted on his attending a reception of the learned societies to be held by the Emperor next day: "Don't try to escape me, or look out for the gendarmes of my letter!"

Thus driven, Fabre paid his first and last visit to Court, but his "five minutes conversation with an Imperial Majesty" was a "distinguished honour" he had no desire to repeat, and all the Minister's gendarmes could not keep him in Paris another night.

Though unattracted by mere worldly success, Fabre was ambitious in his own profession and

dreamed of some day occupying a chair of Natural History. With this end in view, he worked for, and won in 1858, his degree as licentiate in Natural Sciences, and later achieved the crowning academic honour of a doctor's degree. Surely now he had proved himself fitted for University work? But no; a brusque but kindly inspector, M. Rollier, one day enlightened him.

"Have you any money?" he asked.

Fabre had nothing but his paltry salary—"less than the wages of a groom in a decent establishment," he once said in a moment of rare bitterness—and as he was by this time a married man with a growing family, it was more than ever inadequate. Rollier, on hearing this, told him the sordid truth that for University work the one thing needful was a private income. "Be as ordinary, as commonplace as you please," Fabre writes in *The Life of the Fly*, "but, above all, possess the coin that lets you cut a dash. That is the main thing; the rest is a secondary condition."

Fabre was too much a son of the people to be surprised at one more instance of the crime of being poor, and this blunt advice set him experimenting on commercial dyeing as a means of making money. Just at the time that M. Duruy and the Emperor Napoleon were showing him such flattering appreciation, his researches with the vegetable colouring-matter, alizarin, had been so successful that a factory for the use of his dye "rose skywards, full of promises."

Success seemed at last within his reach when

two disasters, in the worldly sense, cut the ground from under his feet. The first was the discovery of artificial means of obtaining madder-dye, which destroyed all hope of making money from the natural product. But this he might have weathered if another reverse even more severe had not befallen him shortly afterwards. Victor Duruy had recently started a movement for promoting the secondary education of girls, and to this work Fabre gladly lent his aid, delivering a set of free lectures in the abbey of Saint-Martial which, by their very success, brought ruin upon him.

"What do girls want to know about natural science?" asked the Church. "Mother Church teaches them all that it is good for them to know."

"What does this 'irregular person, the child of his own studies,' mean by becoming so famous?" said envious treaders in the beaten track. "Let us go and put spokes in his wheel."

"How unseemly," said the old maids of Avignon, "for young ladies to learn intimate details about the lives of animals and plants," and set about plotting to rid the district of this dangerous person.

At head-quarters the same storm was raging, and when, in 1870, Duruy went down under it, Fabre had no more spirit left in him and was ready on the least pretext to throw up the sponge. Now it happened that his house was owned by some of the shocked old ladies of Avignon and they chose this moment of his greatest weakness and discouragement to send him a month's notice to quit. Against this attack, since in the simple

trustfulness of his nature he had asked for no written agreement, he was powerless, and for a moment even his magnificent courage failed. "It is all over," he cried, "the downfall of my hopes is complete!"

But whilst most men of 46 with a wife and five children, faced with loss of home and hopes and the prospect of a premature retirement, would have been permanently crushed, Fabre, after the first shock of the blow, began to recover himself and "to gather up the fragments that remained."

While he was teaching, he had written some school-books which had begun to bring in a little money, and though in 1870, with Paris besieged, even this modest addition to his income was cut off, the success of the books suggested writing as a possible means of livelihood. "Let us try another lever," he exclaimed, "and resume rolling the Sisyphean stone. Let us seek to draw from the ink-pot what the madder-vat and the *alma mater* refuse us. *Laboremus!*"

Fabre's treatment at Avignon had given him a craving for elbow-room, for the quiet spaces of nature, and for the company of self-respecting creatures preoccupied with their own rather than their neighbours' affairs. If it is allowable to take liberties with a familiar saying, one might say that "the more he saw of men, the more he liked insects," and he set about looking for a spot where he could enjoy the society of these boon-companions undisturbed. Homeless at first, he found in due time a little house "alone among the fields," near

Orange, and there he lived for nine years, writing and observing the lives of insects and plants. Although his contact with the outside world was now slight, his family life was quite unspoilt. Like his peasant ancestors, he loved to have his wife and children working with him and he had the gift of inspiring willing service. His son Jules, in particular, was a "zealous collaborator," and this made his death in 1879 a double blow. In that year the family moved to an even more secluded home near the little village of Serignan, where Fabre could realise the wish of his heart for a *harmas* of his own, in which to observe his insects unmolested; but his loss took all the joy out of this achievement, and only his intense religious faith—real, like everything else about him—saved him from despair. Asked as an old man if he believed in God, he answered, "I can't say I believe in God; I *see* Him. Without Him I understand nothing; without Him all is darkness. Not only have I retained this conviction; I have...*aggravated* or *ameliorated* it, whichever you please. Every period has its manias. *I regard Atheism as a mania.* It is the malady of the age. *You could take my skin from me more easily than my faith in God.*"

His work was now more than ever necessary to him and he threw himself with added fervour into it. As "little Paul," one of the younger children, grew up, he showed special enthusiasm and skill in helping his father, and so took, in a measure, the place of Jules; and up to the end of Fabre's long life there were never wanting children or grand-

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children or friends to share his work in the quiet *harmas* or in the indoor laboratory of his retreat at Serignan. There, if any of us had visited this little French village between the years 1879 and 1915, we might have seen him, "in his linen jacket and his heavy shoes," digging in search of food for his mind with the same dogged patience with which his ancestors dug for their livelihood. As he stops work for a moment, "the hair, tossed back, falls in fine curls over the ears, revealing a high, rounded forehead, obstinate and full of thought." The face is clean-shaven and rugged, "full of laborious years; a peasant face, stamped with originality, under the wide felt hat of Provence; touched with geniality and benevolence, yet reflecting a world of energy," while the "two short bristling eyebrows" show the directions in which this energy spends itself, for "one, by dint of knitting itself above the magnifying-glass, has retained an indelible fold of constant attention; the other, on the contrary, always up-drawn, has the look of defying the interlocutor, of foreseeing his objections, of waiting with an ever-ready return-thrust."

Before 1879 Fabre had written some of his *Souvenirs entomologiques*, but it was not till this year that he planned and seriously embarked on the great ten-volume work that was to become so famous. Even as a boy of 15 he had discovered "the magic of words," and these *Souvenirs* are entirely free from what he called the "official jargon" of science, and are delightfully human documents as well as accurate studies of insect life.

Listen, for instance, to this account of the courtship of the scorpions. Two dozen of these had been collected in a great glass cage in the garden, and every night, from the middle of April, a stir would begin in the "crystal palace" and, supper over, the entire Fabre household would gather round to watch. At first all the movement seemed aimless, as a Lilliputian dance might appear to a Gulliver; but gradually, from the confusion of "mingled legs and brandished tails" among "these hideous devotees of gaiety...poses of the highest originality" could be distinguished. "Front to front and claws drawn back," writes Fabre, "two wrestlers assume the acrobat's 'straight bend.'... Then the tails, held vertically erect in a straight line, exchange mutual rubs, glide one over the other, while their extremities are hooked together and repeatedly fastened and unfastened. Suddenly the friendly pyramid falls to pieces and each runs off hurriedly and without ceremony."

Now the two sexes in the scorpion are easily distinguished, for the female is larger and darker than the male; and it was seen that this pose usually occurred between members of opposite sexes, and that when it took place at the meeting of two of the same sex it was "less marked by ceremony" and accompanied by "movements of impatience" and strikings rather than caressings of tails. Night after night the family watched in shifts, and at last Fabre himself discovered that this strange "setting to partners" was usually a preliminary to a lengthy dance or lovers' stroll.

"With the two fingers of each claw" the scorpion seizes "the two fingers of the corresponding claw of the scorpioness in a bunch" and proceeds gently backwards, drawing her after him. "Nothing shows the object which the strollers have in view. They loiter, they dawdle, they most certainly exchange ogling glances. Even so, in my village, on Sundays after vespers do the youth of both sexes saunter along the hedges, every Jack with his Jill." Sometimes, to complete the likeness, he draws her to him and, though she has no face, but only what is to us a "horrible mask," "he gnaws and tickles with his lower jaws the equally hideous mouth opposite. It is all superb in its tenderness and simplicity. The dove is said to have invented the kiss. But I know that he had a fore-runner in the scorpion[1]."

Now all this is not anthropomorphic nonsense, but scientific fact presented in a vivid and untechnical style; each casually mentioned detail was verified by hours of patient watching, and this is the more remarkable when we take into account the fact that the observations had to be made by the light of a lantern, in the open air and at night, and that the principal watcher was an old man of 80, who might have been excused for preferring to spend his evenings comfortably dozing over a fire. The more orthodox scientists condemned Fabre's style, fearing, as he ironically said, "lest a page that is read without fatigue should not always be

[1] For further details and excellent illustrations, see *The Life and Love of the Insects*, chap. XVII and XVIII, A. T. de Mattos.

the expression of the truth." Yet his counter-criticism really goes deeper and justifies his method:

> You rip up the animal and I study it alive;...you labour in a torture-chamber and dissecting-room, I make my observations under the blue sky, to the song of the cicadas; you subject cell and protoplasm to chemical tests, I study instinct in its loftiest manifestations; you pry into death, I pry into life.

Fabre's most important work was undoubtedly on the subject of instincts, and he has thrown much light on the "perfect wisdom, comparable with and even superior to human wisdom," of insects within the "customary conditions" of their lives, and their incredible stupidity outside them. These two aspects of instinct are well illustrated by his work on the Hunting Wasps, which were particularly dear to him as being the subject of his first published paper. Before his day it had been observed that, during the period needed for the rearing of the larva of a certain kind of wasp, called the Cerceris, small beetles of the Buprestis family were found in the nest, and that these, though apparently dead, remained fresh as long as they were needed as food for the larva. The explanation given by Léon Dufour and other naturalists was that the poisonous liquid in the sting of the wasp first killed the beetle and then acted as a preservative of its flesh; but Fabre, on attempting to observe this amazing phenomenon for himself, found that the beetles were not dead but paralysed, the wasp inserting its sting, as an expert surgeon might insert his knife, "into the victim's body, not at

random, which might kill it, but at certain definite points, exactly where the invisible nervous ganglia are located which control the various movements." In this way the beetle is rendered immobile and therefore harmless to the larva, and yet provides it with fresh animal food for the weeks or months of its development.

But while the insect is an excellent routine worker, furnishing the moralist with an excuse for despatching the sluggard to study the ant and the nurse for quoting the tiresome rhyme about the busy bee to lazy children, he is useless at the human art of improvisation. On one occasion Fabre plundered a wasp's nest and found that, after returning to inspect its emptiness, she proceeded to stop up the cell, although there was now no motive for the action. At another time he covered a nest at night with a bell-jar, and no single wasp, thus trapped, attempted to escape, though one *outside* burrowed its way in, as it might have done on finding its nest covered with a fall of earth. Once in, however, this wasp never tried to burrow its way out, but joined its fellow-prisoners in their "futile agitation" against the glass and, in due time, perished with them.

The above are merely a few instances to illustrate Fabre's methods and the general trend of his researches. For a full and consecutive account, his own *Souvenirs entomologiques* must be consulted. These show, as a short account cannot do, the plan on which he worked—how he proved one thing first and then went on to another. This scientific

method of working, combined with his marvellous patience, made him, as Darwin justly said, an "incomparable observer," and the record of his researches is for this reason of permanent value. On the theoretical side his contribution is less important, and he never accepted the doctrine of the origin of species by natural selection. Of Darwin himself Fabre writes that he had "the deepest veneration for his noble character and his scientific honesty," but against the theory associated with his name he waged continual warfare. This attitude of his is hardly surprising when one realises that the facts observed by him are among the most difficult to explain by the Evolutionary Theory, and, further, that he was from the first prejudiced against seeking such an explanation by the tendency, on the part of certain scientists, to regard a belief in Evolution as a substitute for a belief in God.

"Can the insect," he asked, "have acquired its skill gradually from generation to generation, by a long series of casual experiments, of blind gropings? Can such order be born of chaos; such foresight of hazard; such wisdom of stupidity? Is the world subject to the fatalities of evolution, from the first albuminous atom which coagulated into a cell, or is it ruled by an Intelligence? The more I see and the more I observe, the more does this Intelligence shine behind the mystery of things."

This sums up Fabre's own position, but overlooks the important fact that Darwin clearly states that there is no fundamental incompatibility between his theory and a belief in a personal Creator[1];

[1] See the last paragraph of *The Origin of Species*, by Charles Darwin.

while Wallace goes further and develops his reasons for believing, as Fabre did, that the wonderful adaptations of plants and animals, and in particular of birds and insects, are "proofs of organising mind[1]."

One would have liked to read that Fabre himself helped in this reconciliation between the greatest biological theory of his day and his own passionate religious belief; yet, in spite of this lack, his work has value for the scientist and charm for all. He is, before all things, a poet with that touch of divine arrogance that made Browning exclaim:

> The rest may reason and welcome: 'tis we musicians know.

But the harmonies that he makes us hear are so strange and beautiful that we forget his scorn for those who see but do not feel nature, in gratitude for one who, in his search for the truth, never lost his sensitiveness to the beauty that lies at the heart of the universe.

[1] See *The World of Life*, by A. R. Wallace, chap. XIV, "Proofs of Organising Mind."

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FARADAY AND HIS ELECTRICAL DISCOVERIES

> Facts are sterile until there are minds capable of choosing between them and discerning those which conceal something and recognising that which is concealed; minds which under the bare fact see the soul of the fact. HENRI POINCARÉ.

THE boy who comes to London with sixpence in his pocket, enters the office of a great firm, and rises to the position of managing director has become proverbial, and we comfort ourselves, in contemplating our own less distinguished careers, by thinking that he must be an objectionable, pushful person. Let us pause, however, before judging him; sometimes he has mixed motives, like the rest of us, and sometimes he has nobler motives even than our own.

Every well-educated man and woman knows the name of Faraday; most people are familiar with some at least of his more famous discoveries; few —very few—consider how the man himself "arrived." Yet the changes in his fortunes and the widening of his opportunities were as startling as those of the typical business hero.

Michael Faraday (1791–1867) came of sturdy north-country yeoman stock. His father was one of ten children born to Robert and Elizabeth Faraday at Clapham Wood Hall in Yorkshire—a Hall not in the pretentious south-country sense, but merely a farmhouse of rather more dignity and beauty than its neighbours. Little is known of this

large family; one, we read, was a grocer, one a shoemaker, one a farmer. James, Michael's father, was a blacksmith and possessed perhaps some streak of his son's passion for exploring the unknown; at any rate, shortly after his marriage, he made the great venture of moving to London. His wife was Margaret Hastwell, daughter of a farmer at Kirkby Stephen, and they had four children, Elizabeth, Robert, Michael, and Margaret.

Michael was born at Newington in Surrey, but, when he was 5, the Faradays moved to rooms over a coach-house in Jacob's Well Mews, Charles Street, Manchester Square, and this was Michael's home for the greater part of his boyhood. We get an idea of the family's circumstances from the fact recorded that "during the distress of 1801 they received public relief, and to Michael, who was 9 years old, one loaf was given weekly and it had to last him that time."

The Faraday grand-parents and their children were members of a Sandemanian congregation at Clapham. This sect was founded by John Glas, a Presbyterian minister, and his son-in-law, Robert Sandeman, as a protest against the state establishment of religion. The Church, they said, "should be subject to no league nor covenant, but be governed only by Christ and his Apostles." James Faraday and his family identified themselves with the Sandemanian Church in London; and its teaching, and the simple and sincere piety of his parents, played their due part in forming Michael's character.

His father died comparatively young, but his mother lived to enjoy her son's fame. She was particularly "neat and nice in her household arrangements," not a highly educated woman but a devoted mother, living in and for her children; into Michael's work she could not enter, but she was inordinately proud of "my Michael," as she loved to call him. His education, in the narrow sense, was, as he wrote in later life, "of the most ordinary description, consisting of little more than the rudiments of reading, writing, and arithmetic at a common day-school. My hours out of school were passed at home or in the streets."

At 13 he was sent as errand-boy to Mr George Riebau, a bookseller in Blandford Street, close to Jacob's Well Mews. In those days papers were lent out, and one of Michael's less pleasant duties was to ply to and fro on Sunday mornings between tiresome readers who would not relinquish the papers in time and often made the zealous little Sandemanian too late for church. Already his busy mind was working and questioning, and one boyish experiment he records for us. While waiting at a door for a newspaper, he put his head through the railing separating this house from the next and considered which side he was on. The door opening unexpectedly, he "suddenly drew back, and, hitting himself so as to make his nose bleed, he forgot all about his question!"

So much for his boyhood. At 17 we find him promoted to be a book-binder and stationer, "very active at learning his business," but finding time

too for reading many of the scientific books that passed through his hands and for doing such chemical and electrical experiments as "could be defrayed in their expense by a few pence per week."

In 1810 and 1811 he attended some lectures on Natural Philosophy delivered by Mr Tatum at his own house. These lectures had a great effect on Faraday's career, not only on account of the interest of their subject-matter, but because at them he met some leading scientists of the day and, in particular, formed a friendship with Mr Benjamin Abbott, a young clerk in the city. Abbott and Faraday were both keen amateur scientists and corresponded regularly about their experiments and theories. Faraday's letters show from the first how successful his self-education had been. Now and then he makes some modest remark on Abbott's superior education and asks for advice and criticism, but for these there is seldom need. The letters are carefully written, clearly thought out, full of a real passion for knowledge and desire for improvement, with none of the careless and chaotic abandon of the modern scribe of 20, but free too from the tiresome priggishness of the mere bookworm. He takes life seriously but never heavily, and is always ready to poke fun quietly at his friend, himself, or the world at large for their little failings and peculiarities. In one letter he thanks Abbott for sound advice about Cupid and galvanism, adding the wise comment that it was not the first time that the little god had been conquered by philo-

sophy and science; and in another he writes that a dance is going on next door and "the music is so excellent, that I cannot for the life of me help running at every new piece they play to the window to hear them." He does not shun pleasure because he is deaf to its call, but because he is usually too busy listening for the whispered secrets of nature to attend to other voices.

In 1812 Faraday attended a few of Sir Humphry Davy's lectures at the Royal Institution, took notes, and afterwards "wrote them out more fairly in a quarto volume." "Later in the year," so he wrote to a friend, "being anxious to escape from trade, which I thought vicious and selfish, and to enter into the service of Science, which I imagined made its pursuers amiable and liberal," he took the "bold and simple step" of writing to Sir Humphry, enclosing the notes of his lectures. The result of this was the offer, a few months later, of a post as laboratory assistant at the Royal Institution, accompanied by a letter from Davy warning him that science is a "harsh mistress, and in a pecuniary point of view but poorly rewarding those who devote themselves to her service." In this case she offered Faraday 25*s*. a week and two rooms at the top of the house; needless to add, he accepted.

The next six months were full of interesting experiences, whether in acquiring skill and knowledge in the ordinary routine work of the laboratory, sharing with Davy the risks of pioneer work on explosive compounds, or sitting attentive under some lecturer, making mental notes of his idio-

syncrasies for the amusement and edification of himself and his friend Abbott. In this year, too, he joined the City Philosophical Society, an association of "thirty or forty individuals, perhaps all in the humble or moderate rank of life," who met every Wednesday either to hear a paper or to discuss among themselves. Faraday's zeal for self-education was such that he even collected some of these humbler scientists on Saturday nights "to read together, and to criticise, correct, and improve each other's pronunciation and construction of language. The discipline was very sturdy, the remarks very plain and open and the results most valuable."

In the autumn of this year, 1813, Faraday was offered and accepted a post as philosophical assistant to Davy in a proposed tour in Europe[1]. Think what this journey must have meant to him. He was now 22, already a well-educated man in his own sphere, yet he had never been beyond 12 miles from London and had had few opportunities of studying first-hand the worlds of nature and of men. His accounts of his first impressions show a characteristic mixture of simplicity and shrewdness. The scenery of Devonshire causes a "revolution in his ideas respecting the nature of the earth's surface," he forgets the cold of a winter's drive through the forest of Fontainebleau in marvelling at the magic wrought by a thick mist which "had, by being frozen, dressed every visible object in a

[1] Although England was at war with France, Napoleon granted Davy permission to travel on the Continent.

garment of wonderful airiness and delicacy," or whiles away a half-hour on a dark night's journey studying his first glow-worm, which unfortunately succumbed to his attentions—"it must have been in a very weak state when I found it" is his boyish excuse.

His comments on things French are thoroughly British. The French are queer fellows, making much ado about nothing in examining luggage for contraband and in unloading the ship, "their dishes are to the taste excellent and inviting, but then they require, whilst on the table, a dismissal of all thoughts respecting the cookery or kitchen," and their pigs—why in the distance their pigs look like greyhounds!

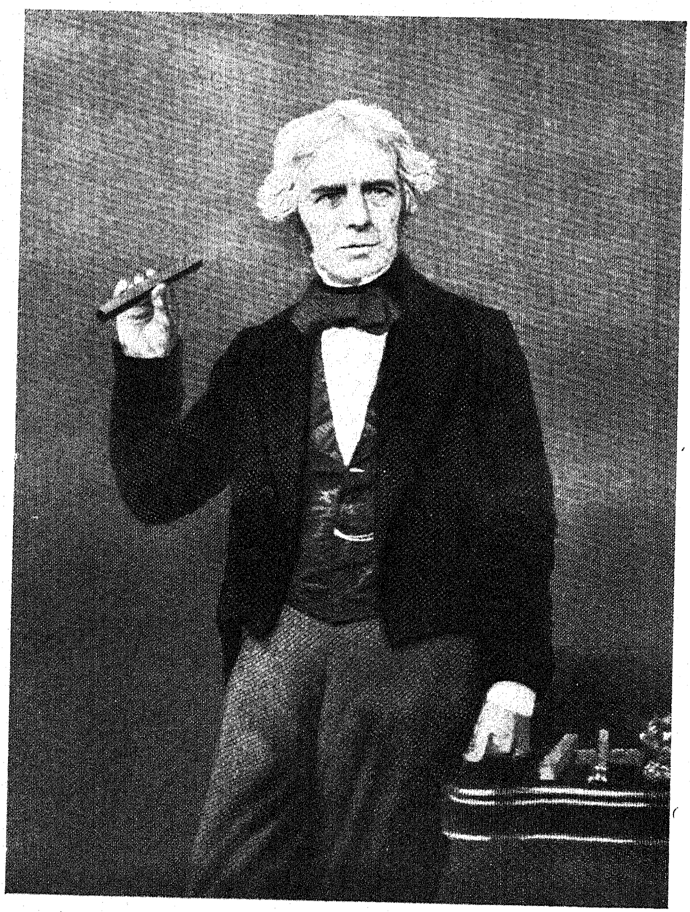
Someone once wisely said that men's characters are formed by the part of their environment to which they attend. In the same month that Davy and Faraday crossed the English Channel, Wellington defeated Marshal Soult in the Pyrenees and our allies beat Napoleon in the Battle of Leipzig. Of these clashings of the nations we get only occasional glimpses from Faraday's letters; they were interesting and important, but not in the foreground of his thoughts. In December 1813, three months before Napoleon took his forced journey to Elba, Faraday saw him driving in state through the Tuileries Gardens; the magnificence of his clothes, carriage, and attendants was striking, as was the fact that "no acclamation was heard...and no comments." Another day he visited the Galerie Napoléon and described it as "the glory and the disgrace

of France," the glory because of the splendour of the works of art collected there, the disgrace because, to gain them, the French had "made themselves a nation of thieves."

In the background the changing face of nature, ever new and wonderful, and the march of the nations, strange and terrible; and in the foreground—what? One day in Paris it is filled by Ampère, Clément, and Desormes showing Davy some iodine, a substance discovered two years before by M. Courtois, a saltpetre manufacturer, but still new to the scientific world; on another by Gay-Lussac lecturing at the Ecole Polytechnique; and on a third in Geneva by Volta, "a hale elderly man bearing the red ribbon, and very free in conversation." At other times inanimate things fill the stage—the voltaic battery maintained by the French Government and "composed in 6 troughs of wood, each containing about 100 pairs of plates of 7 or 8 inches square"; Galileo's first telescope, "a simple tube of wood and paper, about 3½ ft. long, with a lens at each end"; or the wonderful collection of electrical apparatus at the Academy del Cimento in Florence. In Paris whole days were spent in the laboratory conducting researches on iodine; at Montpellier Davy "continued to work very closely on iodine," searching for it in sea-weeds, but did not obtain "certain evidence of its presence"; at Florence he and Faraday succeeded in burning a diamond in oxygen, concentrating the heat from the sun's rays upon it by means of the "great burning-glass of the Duke of

Tuscany," one of the treasures of the Academy del Cimento.

In the spring of 1815 Faraday returned to England and to the Royal Institution, where he spent the rest of his scientific life. His ability had already made him a marked man, and from this time the scope of his work and opportunities widened steadily. In 1816 he gave his first lecture to the City Philosophical Society, and in his notes on this and other early lectures can be discovered some of the secret of his success as a lecturer. He left nothing to chance; his matter was most carefully prepared, his experiments rehearsed, and his delivery improved by lessons in elocution. Eleven years later he delivered his first lecture at the Royal Institution. As he faced his audience there, how vividly he must have recalled those other lecturers of 15 years before and that attentive young assistant, making notes not merely of the interesting matter of their lectures but also of the mistakes in their manner of presenting it! Faraday's critical faculties were, however, never used for barren criticism alone, and his youthful study of the art of lecturing combined with his natural gifts to make him the most famous scientific lecturer of his day. He regarded lecturing as an art and brought it to such perfection that no trace of art remained; his manner was absolutely natural, his sympathy with his audience perfect, and his explanations such that the ignorant could understand enough to be interested and the learned could follow him "beyond the bounds of their own knowledge." If he were



MICHAEL FARADAY

presenting his own work to his audience, he "appeared to be trying only to enable them to judge what his latest discoveries were worth," and, if that of others, "one object, and one alone, seemed to determine all he said and did, and that was, 'without commendation and without censure, to do the utmost that could be done for the discoverer.'"

Great as was Faraday's fame as a lecturer, it is by his original researches that his name lives. So numerous are these that it is impossible even to name them all here. Tyndall, Faraday's successor and friend, gives an admirable short account of them in *Faraday as a Discoverer*. He likens Faraday's discoveries to a mountain range in which the general level is high but here and there a mighty peak stands out dominating the rest. Those who have curiosity and perseverance to explore these heights for themselves must consult Tyndall's book or Faraday's own writings; others must be content to view from afar a few peaks, such as an account of this sort can point out to them.

Ohms, ampères, volts, and farads are familiar words in the vocabulary of science; galvanometers and voltameters are familiar objects in every laboratory, sometimes unfortunately treated with the careless contempt that familiarity is said to breed; but they assume a new importance when we realise that all these words are memorials to the work of individual men—Faraday and his great contemporaries, Galvani, Volta, Ampère, and Ohm.

In 1820 Oersted in Copenhagen discovered the action of the voltaic current on a magnetic needle;

Ampère in France immediately afterwards worked out the connection between magnetic phenomena and electric currents; and Wollaston in England was feeling out towards the idea of electro-magnetic rotations. In April 1821 Wollaston attempted in the laboratory of the Royal Institution to cause a wire in a voltaic circuit to revolve on its own axis. Faraday did not see this experiment, which was unsuccessful, but heard some talk about it and knew of Wollaston's theory that there is a power connected with a voltaic current *which acts not to or from the circuit but in circles round it*. Little wonder that his mind was astir with interest and speculation on the subject, that he read much about it and devised experiments to put his own and others' theories to the test of fact.

In the midst of this absorbing work, on June 12th, 1821, he married, and was allowed to bring his young wife to his rooms at the Royal Institution. Chesterton once wisely said that literature usually deals with unhappy marriages, not because they are the rule, but because domestic bliss is not dramatic. Faraday's married life was, in this sense, happily undramatic; years later, in some autobiographical notes, he described his marriage as an event which more than any other contributed to his earthly happiness and healthful state of mind, adding: "The union has continued for 28 years, and has nowise changed except in the depth and strength of its character."

A month after his marriage he made his confession of sin and profession of faith necessary for

his reception as a full member of the Sandemanian Church. So sacred did this step seem to him that he did not even tell his wife of his intention to take it. "That," he answered, when she questioned him on his silence, "is between me and my God."

In the autumn of this year he wrote, by request, a History of Electro-Magnetism, and, following an excellent custom of his, repeated all the experiments to which he referred. He attempted in vain to make a wire carrying a current rotate on its own axis, but succeeded in making it rotate round a magnet and also in making a magnet rotate round the wire. On Christmas Day, 1821, he called his wife to witness, for the first time, the revolution of a magnetic needle round a current. History does not record what Mrs Faraday said, but we may be certain that she was wiser and more sympathetic than the lady who, after seeing another of Faraday's simple but significant experiments, asked "What is the use of it?" "Madam," Faraday was inspired to reply, "what is the use of a new-born child?"

"The great experimentalist must ever be the habitual theorist," writes Tyndall, but the theory must be the handmaid of the fact. Faraday said of himself as a boy that he was a "lively imaginative person, and could believe in the 'Arabian Nights' as easily as in the 'Encyclopædia.' But facts were important to me and saved me." Tyndall completes the picture by saying, "To him, as to all true philosophers, the main value of a fact was its position and suggestiveness in the general sequence

of scientific truth." Our knowledge is never more than a small bright spot surrounded by clouds that cover we know not what; Faraday worked at the "very boundaries of our knowledge," and his mind habitually dwelt in this "boundless contiguity of shade" and yet was never clouded by it. His thoughts, ever ready to roam the universe of time and space, could at will be concentrated on some apparently trivial experiment and made to note impartially expected and unexpected effects.

From 1821 to 1831 Faraday was steadily adding to his and the world's knowledge by reading, experimenting, and lecturing. One problem in particular challenged his attention. Electrified bodies charge unelectrified bodies by induction; why, then, should not a wire carrying a current induce a current in another? Why not?—only that many men had tried to get this effect and failed. But Faraday, of course, must try for himself. He made a spiral of two insulated wires round the same wooden cylinder. He connected one wire with ten cells and the other with a galvanometer. No effect. Not to be beaten, he increased his cells gradually from 10 to 120, and still, while this strong current flowed in the one circuit, the galvanometer needle lay idle in the other. Faraday would have been a difficult man to gull with conjuring tricks, the art of which lies in doing something at the moment when the audience least expects it. He expected an effect while the current was flowing, but his watchful eye caught the little unexpected kick of the needle as he made, and again as he broke, the

battery circuit. This momentary "induced" current was always in the opposite direction to the "inducing" current on making, and in the same direction on breaking, the battery circuit. It could also be produced in a closed curve of wire simply by moving it towards, or away from, another in which a steady current was flowing.

The work already mentioned of Oersted, Ampère, Wollaston, and, above all, of Faraday himself has shown the close connection between magnetic and electric phenomena. What more natural than to try next the effect of changing the magnetic conditions near a closed circuit not containing a battery? This Faraday did in various ways and always with the same result: the needle of the galvanometer in the circuit gave a kick—a momentary electric current was, in fact, produced. In the simplest form of this experiment a permanent steel magnet is thrust suddenly into the coil of wire, "not quite through but only half through," Faraday says in his notes; "if passed wholly through, the needle stops as by a blow." When the magnet approaches the coil, the kick is in one direction; when it is withdrawn, in the other. The kicks are feeble, not at all impressive. What is the use of the new-born child? Developments from these simple experiments have given us the dynamos and motors of to-day. Was the new-born child not worth the care and interest lavished on it? Tyndall—no mere Boswell to Faraday's Johnson, but himself a scientist of note and proved judgment—writes that, in his opinion, "this discovery of Magneto-electricity is

the greatest experimental result ever obtained by an investigator. It is the Mont Blanc of Faraday's own achievements."

Faraday's mind was essentially that of a philosopher—"he saw life steadily and saw it whole." His greatest work was inspired by the hope of finding links between the different phenomena of nature; his greatest experimental triumphs were those that brought these links from the realm of faith into that of fact. The series of experiments on the mutual action of magnets and currents showed the close connection between electricity and magnetism; another group, hardly less important, established a link between chemical and electrical actions.

In every text-book of electricity we find quoted Faraday's Laws of Electrolysis. In every book dealing with chemical preparations we read again and again that the method used is an electrolytic one. The very words are Faraday's. His contemporaries knew that, if an electric current passes through a liquid, decomposition results. They believed that this was caused by attraction between the "poles"—metal plates conducting the current into and out of the liquid—and the "bodies separated by the current." Faraday's experiments showed that these bodies are, apparently, not attracted by the poles but "ejected by the current." The word pole was, he felt, connected with the idea of attraction, so he substituted for it "electrode," distinguishing the two by calling the positive pole the "anode" and the negative the "cathode."

The substance decomposed he called the "electrolyte" and its constituents "ions," "anions," or "cations," according to the electrode to which they were going. When a current passes through a liquid, decomposition results. Does the same current always produce the same amount of decomposition? If so, could not the amount of decomposition be used as a measure of voltaic electricity? Faraday asked himself these questions and answered them, as usual, by a series of careful and ingenious experiments. First of all he took some cells, fitted them up with electrodes of various sizes and shapes, filled them with slightly acidified water, and connected them in series, so that the same current passed through each. He collected the gases given off at the various electrodes and found that the same quantities were liberated at all the anodes and the same at all the cathodes. He changed the strength of the acid in his battery, he added different amounts of dilute acid to the water in his cells, and, in each case, the result was the same. "The amount of electro-chemical decomposition depends, not upon the size of the electrodes,...not upon the strength of the solution, but solely upon the quantity of electricity which passes through the cell." This is the first of Faraday's Laws of Electrolysis. It is more usual now to state it in terms of current, and it then runs:

> The amount of substance decomposed in a given time is proportional to the current.

This discovery enabled Faraday to realise his hope of using the amount of chemical decomposi-

tion as a "measure of Voltaic Electricity." His "Voltameter" was similar to the cells referred to above, except that the tubes for collecting the gases given off were graduated so that the volumes could be read directly. To test the soundness of this method, Faraday thought it advisable to introduce cells containing electrolytes other than acidified water into the same circuit with the voltameter, in order to discover whether there is a constant relation between the amounts of different substances liberated by the same current. First of all he chose tin chloride; this is a non-conductor when solid but a conductor when fused, tin being deposited on the cathode. He allowed the same current to flow through the voltameter and through a cell containing fused tin chloride. When a "reasonable amount of gas" had been liberated in the voltameter, he broke the circuit, read off on the graduated tube the volume of gas collected, and found the weight of tin deposited. An easy calculation gave the weight of water decomposed; another the weight of tin that would be liberated by the current needed to decompose the equivalent weight of water. *This weight was almost exactly the equivalent weight of tin.*

Faraday took other substances, some of them solutions and some fused compounds, some in which the decomposition was simple—as in the case of tin chloride—and some in which it was complicated by "secondary actions." He connected them, sometimes singly and sometimes in series, with the voltameter. His mind was ready

to leap to the general law, of which the tin experiment was typical, but he held it in check till he had given the facts every opportunity to declare themselves for or against. The verdict was unanimous and is summed up in the second of Faraday's Laws of Electrolysis:

> The amounts of different elements set free in a given time by the same current are proportional to their equivalent weights.

The discoveries of magneto-electric induction and of these great laws of definite electro-chemical decomposition are those by which Faraday's name will live; but his amazing activity of brain and resource in experiment led him to others hardly less important and covering a most varied field. The importance and range of his work and the charm of his personality brought him into the ranks of the most famous scientists of his day and earned him no less than ninety-five honours of various kinds from learned societies throughout the world. Cultured people of Faraday's time did not really understand the significance of his discoveries, did not even see their commercial possibilities; but they flocked to the lectures of this strange, winsome enthusiast, and the Government of the day marked their sense of the value of his work by voting him £300 a year.

In 1858 the Queen gave him, when his life-work was over, a house on Hampton Court Green, and there he and his wife lived for the closing years of his life. The wonderful brain was wearing out at

last. Life was happy still but no longer a series of high adventures. Only the final adventure remained, and he set his face calmly towards it. In this, as in his work, faith and hope sustained him—a deeper faith and a higher hope—and led him on, eager, towards the great experiment. On August 25th, 1867, he passed quietly away in his study chair. His body was laid in Highgate Cemetery, the spot being marked, according to his wish, by a gravestone "of the most ordinary kind."

A great scientist, but more than a scientist—

> Take him for all in all, he was a man;
> We shall not look upon his like again.

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THE CURIES AND THE DISCOVERY OF RADIUM

Let us try to reach the inner life of something great or small. The truly useful knowledge is mastery. PROFESSOR MIALL.

There is no new ideal imaginable by the madness of modern sophists which will be anything like so startling as fulfilling any one of the old ones. G. K. CHESTERTON.

IN the reaction against Victorian conventions and bourgeois respectability the modern world has developed an equally futile worship of mere freedom and change. On no subject has more nonsense been talked by both conventionalists and lovers of freedom than on that of the relations between men and women. Where married people are concerned, this department of life is so essentially private and personal that the world, as a matter of fact, knows little about it except in cases of glaring failure or unusual success on the part of people of some fame or notoriety. When Count Rumford locked his gates on his wife's friends and she poured boiling water on his favourite plants, the neighbours must have guessed that the *rapport* between them was imperfect; at the other extreme, when men worked in the same laboratory with M. and Mme Curie or met them in the intimacy of their own home, they could not fail to be aware of the sympathy of heart and mind that existed between them.

That this inner harmony contributed not only to the Curies' private happiness, but also to the success of their scientific work, can hardly be doubted by anyone who reads Paul Langevin's

account of his friend and master, Pierre Curie. Before his marriage he was a man to love and look up to, a man of high ideals and clear and honest thought; but his wife increased his power ten-fold, giving him the joy of living in contact with a mind possessed, like his own, with the passionate desire to see clearly and understand deeply, and the comfort of a steady will and affection to lean upon in times of doubt and difficulty.

Historically, it was Mme Curie who discovered radium, and Pierre Curie was always eager to give her the place of honour to which she is entitled; but it is difficult to believe, as one reads of their life together, that she would wish to regard it as other than their joint achievement. Their research-work was built on a common stock of knowledge, and their never-ending task of thrashing out ideas and testing facts was guided by "la finesse d'esprit de Curie" and sustained by "la persévérante clarté de sa femme."

This is a picture of the stimulating and fruitful companionship enjoyed by Pierre and Marie Curie in their married life, but it is incomplete till we have filled in the background against which it is set. It is curious that, as regards their immediate circle, they both, unlike most of the great scientists, grew up in surroundings which gave full play to their individual tastes, but their wider, national environments were completely different.

Pierre Curie (1859–1906) was the second son of Dr Curie, a doctor in Paris whom Langevin describes as "homme de science, ennemi de toute

servitude morale et matérielle, dogme ou préjugé." Pierre and his brother Jacques were encouraged by him to develop on their own lines, and so learnt to get into touch with nature and to love concrete facts and first-hand knowledge. Pierre had no skill or quickness in mere routine lessons or in subjects of which he could not see the use; in mathematics, however, which he regarded as a means to an end in the study of physics, he made rapid and remarkable progress. In all his work he had the courage to recognise and to say when there was anything that he did not understand.

The two brothers were firm friends, different in temperament but alike in their love of science. Jacques was the man of action, robust and full of life; Pierre was the thinker and the idealist, and, like all "whom an ideal torments," had his times of doubt and depression. A private journal, kept by him in his early twenties, shows us that he was not exempt from the common experience of the young, but found himself constantly distracted from his efforts to realise his dream by "les mille séductions de la vie extérieure si puissantes à son âge." He had, however, the insight to see that the solution of his problem lay not in denying the sweet and natural claims of life—eating, drinking, taking one's ease, loving—but in subordinating them to the often conflicting claims of the life of thought to which he had pledged himself. "Il faut faire de la vie un rêve et faire d'un rêve une réalité," he wrote: only by idealising the real can we realise the ideal.

Besides his love of science, he possessed great sensitiveness to all beauty, especially as expressed in music and in wild nature. Sometimes he would spend whole nights alone in the woods. One valley, in particular, he remembered with delight; the tangle of damp, sweet-smelling plants, the fairy palace of arched hops, and the hillsides dappled with purple heather filled him with a sense of well-being and sent him home with a score of ideas dancing through his head.

The two brothers had their first systematic science teaching from Prof. Leroux, and in these early days their spirit of enquiry sometimes outran their knowledge. One day, for instance, Jacques had the ingenious idea of doing some original research on the electromotive force generated by plunging an electrode of sodium into strong nitric acid. The havoc wrought by this and like experiments caused their master to shake his head over them and to conclude, "qu'on ne ferait jamais rien de ces petits Curies."

Pierre passed his licentiate in physics in 1878 and at the age of 19 became assistant to Desains in the Science Department at the Sorbonne. Jacques, too, was at the Sorbonne by this time, but in the Organic Chemistry Department under Friedel. The two brothers, however, continued to work together, and during the next four years did some important research work in piezo-electricity, or the production of electricity by the compression of crystalline substances.

In 1882 Pierre Curie left the Sorbonne to become

"chef de travaux" (chief of the laboratory) under Schützenberger at the School of Industrial Physics and Chemistry, which was at that moment being started in Paris. Six years later Paul Langevin came to this school as a pupil, and from him we get a first-hand picture of Pierre Curie at this period of his life. From the first, when he was little older than his pupils and therefore might have been excused for standing on his dignity, he was their comrade and friend as well as their master, and he had the happy gift of attaching them to himself equally by his wide knowledge and by his unaffected goodness. When Langevin entered the school, ten years of work in a laboratory had given Curie a mastery of his apparatus and a power of clear explanation which impressed even the ignorant novice. There was ease mixed with diffidence in his bearing, and it was a joy to his pupils to work with him, because they felt that he worked with them. Langevin's happiest memories of Curie at this time are of him as he stood before his black-board, chatting with his class and starting, by his keen and infectious curiosity and by the breadth and accuracy of his learning, fruitful trains of thought in their minds.

In this way thirteen years slipped quietly away in happy absorption in his work, his pupils, and his family. Sometimes his father would express uneasiness because he was not yet a doctor, but to this Pierre would always reply that there was no hurry and that he was quite content as he was. He feared any change of work or position, in case

it should mean that he would have less time for research.

In the worldly sense, he had no ambitions; but in the inner recesses of his being he cherished the hope of some day finding his ideal mate, a woman who could be his collaborator as well as the mistress of his heart. "Ce serait une belle chose à laquelle je n'ose croire de passer la vie l'un près de l'autre hypnotisés dans nos rêves." He put it from him as an idle dream, yet the dream came true; for he found, in the person of a brilliant young Polish girl, working in the laboratories of the Sorbonne, all that his nature sought and needed.

Marie Sklodowska[1] was born on November 7th, 1867, in Warsaw. Her father was a science master in the *gymnasium* of that town; her mother died young, leaving a family of small children. Dr Sklodowski[1] had a real passion for science, and emphasised, especially in the teaching of physics, the importance of practical illustrations. On this point he had continual disputes with the classical master, who held that experiments in physics were child's play. This being the general opinion, the funds set aside for equipping the laboratory were quite inadequate and Dr Sklodowski had to buy much of the necessary apparatus out of his own pocket. He could not possibly afford to pay anyone to wash his bottles or keep things in order, and so welcomed his little daughter, Marie, when she took to coming into the laboratory, covered with a large apron and armed with towels, and tidying up for

[1] "Ski" is the masculine and "ska" the feminine ending in Polish.

him in a motherly and competent way. At first, he regarded this help as a childish game, similar to that of "dusting like mother" or playing with dolls; but soon he found to his delight that she was really interested in what went on in the laboratory, and, from the moment of this discovery till she was old enough to go to school, he taught her regularly.

When she began going to the *gymnasium*, she still kept up her custom of helping her father and, as she grew older, she could be trusted to set up in the evening the apparatus for the next day's work. Dr Sklodowski often went through his entire lecture over-night, and in this way Marie's scientific education continued in the evenings, while her general education received attention at the *gymnasium* during the day.

In the laboratory all was peace and studious work; but outside there was oppression and seething discontent. Warsaw is a great centre of Polish culture, and this, in every form, it was the policy of the Czardom to crush; the Polish language must not be taught, the national dances must not be performed, or the national hymns sung. The result of this tyranny was that every Pole was filled with a flaming patriotism; Polish was studied as it had never been studied before, the children learning it "with a Russian book on top of the desk, a Polish one beneath"; and "everybody who was anybody...was a revolutionist, ready at any time to taste misery in Siberia for the holy cause." As Marie Sklodowska grew up and listened to the talk

of her father and his students and friends, she too was fired with the patriotism that regards death and exile as trivial incidents, and joined the ranks of the rebels.

Details of this period of her life would be of immense interest, but all the information available is contained in a brief paragraph in Dr Benjamin Harrow's book on *Eminent Chemists of Our Time*: "Meetings were held, plans drawn, and prayers offered for the success of the independent movement. Unfortunately, the police got wind of the affair. A number of Dr Sklodowski's students were among the ringleaders, and Marie herself was more than a mere onlooker."

The reticence of Madame Curie on this subject, while showing the fine trait of dislike of self-display, is perhaps also a tragic sign that the shadow of the Russian tyranny still falls on Polish minds, though the substance of it is happily a thing of the past.

The sequel to this incident was that Marie Sklodowska decided to leave Warsaw in order to study science in some freer atmosphere. She first thought of Cracow, the former capital of Poland and at that time under Austria, the least oppressive of Poland's masters. Rumour has it that the secretary of the historic university there, on being asked to enter her as a "student of physics and chemistry," told her that "this sort of study was not for her; he would put her down for the cooking-class!" Whatever the truth of this story, the fact is that she did not go to Cracow, but decided to try her fortunes in Paris.

MARIE SKLODOWSKA CURIE

In her early twenties, then, she began her life of exile in a foreign capital, with no money and few acquaintances and only her brains and her courage between her and starvation. "She established herself in the 'east side' section of the town, in a small back room, four flights high, to which she carried her own coal. Her diet consisted of bread and milk for so long that, as she herself has said, she had to acquire anew the taste for wine and meat. Ten cents were her daily expenses, and this she made largely by private tutoring, and, later, by preparing the furnace and washing bottles at the Sorbonne[1]."

The knowledge shown by Marie Sklodowska in performing her menial tasks at the Sorbonne attracted the attention of two men of influence there, Gabriel Lippmann, head of the Physics Department and famous for his colour photography, and Henri Poincaré, a great mathematician and brother of the statesman. They discovered her history, Lippmann communicated with her father, and the outcome was that "Marie was put into the hands of Pierre Curie, one of Lippmann's most promising pupils."

Marie Sklodowska was at this time, though broad-shouldered, not ungraceful; her mass of fair, wavy hair, brushed back, showed her magnificent brow, from beneath which her blue-grey eyes looked out with a steady gaze. She has the high cheek-bones of the Pole and a firm mouth and chin, but in the face and in the musical voice,

[1] Harrow's *Eminent Chemists of Our Time*, p. 158.

which Pierre Curie grew to love, there was gentleness as well as strength. She combines, like so many Polish women, a love of knowledge with a love of beauty, and yet her wide culture sits lightly on her shoulders and her manners are simple and natural.

Pierre Curie's nature was in some ways like and in others complementary to hers. In appearance he was tall, thin, and slightly stooping, his stubborn hair prematurely grizzled over his fine temples, his expression frank and lit up by a smile which revealed his exquisite goodness of heart; in temperament he was somewhat prone to moods of despondency, set off by moods of boyish gaiety. Temperamentally they were contrasts, but in their tastes they were alike—alike in their passion for clear thought and deep understanding and in their love of simple pleasures and of beauty in nature and in art.

Both were poor and both loved their work, but they decided that neither of these facts need prevent their marrying; Pierre could go on with his researches on electrometers and condensers and Marie could help him and work for her degree. In 1895, therefore, when he was in his thirty-sixth and she in her twenty-eighth year, they started their married life together. From the first it was one of co-operation, not only in the laboratory but in the home, and visitors to their simple ménage would find Pierre sweeping the floor while his wife cooked the meals. This arrangement enabled Marie to continue her scientific work, and within three

years she had passed brilliantly her licentiate in mathematics and physics. They lived first at Sceaux, then, finding that too far out, they moved nearer to the laboratory where they both worked. In 1898 their first child, Irene, was born. Shortly after her birth, wishing to give her more light and air and also to take in Pierre's father, who had recently lost his wife, they moved to a house in the Boulevard Kellermann, near the Montsouris Park.

The Curies wisely kept the number of their friends small—"n'aimant pas plus disperser leurs affections que leur esprit"; but here, in the evenings, the chosen few could always find them in the principal room, where they worked together, overlooking the garden which the old grandfather kept in order. They both believed in work and had no use for idle talk, but they welcomed the play of mind on mind with each other and among their friends, and many an evening was spent in long discussions of the subjects that most interested them.

They had many topics, but the one to which the conversation was most apt to return was "the marvellous movement in physics, in which their joint work now holds so important a place." As early as 1860 some observations had been made on the properties of rarefied air in a tube through which electricity was passed, and in 1879 Sir William Crookes had discovered the "cathode rays." Considerably later, Sir Joseph Thomson and others showed that these rays consist of nega-

tive particles of electricity, or "electrons," each electron weighing less than a thousandth part of the hydrogen atom. In these facts alone there was food for thought and discussion among those brought up on Dalton's Atomic Hypothesis; but in 1895, the year the Curies married, still further attention was attracted to the subject by Röntgen's famous discovery of X-rays, produced when the cathode rays impinge on matter, and capable of penetrating flesh and other opaque substances and of affecting a photographic plate through black, light-proof paper.

This group of discoveries stimulated research on the properties of electrons and of radiations of all kinds in numerous laboratories in Europe and America; but it happened to be Becquerel, a colleague of the Curies in Paris, who, in 1896, stumbled, one might almost say, upon the entirely new phenomenon of radio-activity. He was examining the behaviour of fluorescent substances (that is, substances capable of "absorbing light and re-emitting it, changed to a colour characteristic of the fluorescent substance") and among these were included salts of uranium, which fluoresce with a bright greenish-yellow glow. While working with these uranium compounds, he observed, in addition to the fluorescence, other radiations which, like X-rays, can penetrate opaque substances and affect a photographic plate. He also made the important discovery that the air round these new rays is "ionised," for it will cause the gold-leaves of a charged gold-leaf electroscope to collapse.

Following up Becquerel's work and using his method of testing for the presence of these radiations by their action on a gold-leaf electroscope, Mme Curie undertook an exhaustive study of all the known elements and their compounds, to see whether any of them showed signs of this "radio-activity" observed in the case of uranium. Thorium, however, was the only known element that showed the slightest sign of sharing with uranium this "ray-emitting power."

This line of research might have ended here if Becquerel's method of *detecting* ionisation, and through it radio-activity, had not also furnished a means of *comparing* the radio-activity of different substances. The gold-leaves of the electroscope do not collapse instantaneously, and the rate at which they do so can be used to measure the radio-activity of the substance under consideration. In testing a sample of pitchblende, the commonest ore of uranium, in this manner, Mme Curie was surprised to find that it showed more than four times as much radio-activity as could be accounted for by the uranium present in it. What could this mean but that some unknown and radio-active element is present in pitchblende?

Pierre Curie was at this time engaged in a line of research of his own, but this he readily abandoned to join forces with Mme Curie in the task of discovering and isolating this new element, which, their calculations showed them, could only be present in pitchblende in minute quantities. Their best hope of success lay in working on a very

large scale; but how, with their slender income and the many calls upon it, could they afford to buy the necessary amount of the ore? This initial difficulty was overcome by a generous and timely gift from the Austrian Government, which owned uranium mines in Bohemia, of one ton of pitchblende, from which the uranium had been extracted. This enabled the Curies to embark on the task they had set themselves, a task not unlike that of looking for a needle in a bundle of hay. Anyone who has had the slightest experience of separating a pure substance, even from an ore of which it is the principal ingredient, can form some dim notion of the skill and patience needed in the attempt to isolate an unfamiliar, and possibly non-existent, substance from a complex ore, which, if it contains it at all, contains only small traces of it.

The method used was repeated fractional crystallisation, and at first the quantities of material handled were so great that the work had to be done in a factory. In its later stages, it shrank to the more manageable dimensions of a laboratory, and, through the kindness of Schützenberger, Mme Curie was allowed to work at the Industrial School with her husband. There, in a tumble-down wooden building, their friends would find them, Mme Curie clad in a laboratory over-all and Curie wrapped up warmly as a protection from the rheumatism that the place was apt to give him, busy over their experiments with radio-active substances.

The progress of their work was inevitably slow,

but gradually the radio-activity was proved, by means of the electroscopic examination, to be associated with the fractions separating with bismuth and barium respectively. After many trials a strongly radio-active substance was partially separated from the bismuth fraction, and this Mme Curie called *polonium*, in honour of her country. The radio-active constituent of the barium fraction proved to be even more powerful than polonium and even more difficult to separate. Mme Curie gave the name of *radium* to this new element and, after "some of the most exhaustive and painstaking experiments in the history of science," succeeded in isolating one of its salts.

This pioneer work, which lasted, roughly, from 1898 to 1902, was not only difficult but, as gradually became apparent, dangerous. The continual stream of energy given off by a radio-active substance is harmless when spread through a vast mass of inactive material, but when even a small quantity of a radium salt is concentrated in one spot, it is a source of danger as well as of possible good to man. Before safe methods of keeping and handling radio-active substances had been devised, much suffering was caused to those working on them. Mme Curie's health does not seem to have been permanently injured, but Pierre Curie's suffered considerably and his hands were badly crippled from contact with radium tubes; perhaps, when he discovered the danger of their work, he insisted on taking the lion's share of the risks.

In 1903 Mme Curie presented the results of her

researches to the Paris Faculty of Science as a dissertation for her doctor's degree, and the publication of this thesis carried her at a bound from obscurity into fame. A few leading scientists, notably Lord Kelvin in England, had for some years taken a keen interest in the Curies' work; but as late as 1900 so little was known of it among physicists in general that, when Becquerel showed Mrs Ayrton, in her laboratory in London, a tiny packet containing a precious sample of radium bromide, she heard of "Madame Curie of Paris" for the first time. In the cause of science the publicity now given to the Curies' discoveries had, no doubt, its advantages, but their sudden popularity was an unwelcome interruption of their quiet life in home and laboratory. They evaded, as far as possible, all attempts to lionise them, refused interviews to reporters and photographers, and retained in their hour of fame the simplicity of heart and soundness of judgment which had characterised them in their years of obscurity.

In this same year, 1903, the Curies came over to London, at the invitation of Lord Kelvin, in order that Pierre Curie might deliver an address to the Royal Institution. The reception of them both on this occasion was a real triumph and the Davy Medal of the Royal Society was awarded to them jointly. The Nobel Prize for that year, "the highest mark of distinction that can come to any scientist," was divided between them and Becquerel.

The retiring character of the Curies, their unwillingness to court influential people, and Pierre

Curie's generous habit of singing the praises of his rivals had up to this time prevented him from obtaining a post worthy of his talents; but in 1904 a department at the Sorbonne was specially created for him, and Mme Curie was appointed "chef de travaux" under him.

For the first time their income was adequate to their needs, and it seemed as if a period of tranquillity and even greater usefulness lay before them. Another little daughter, Eve, was born to them, and their work and family interests filled their time and thoughts happily.

One day, early in 1906, Pierre Curie left home to lunch with a circle of his intimate friends. Langevin was among them and watched his dear master, more gay and full of life than he had ever seen him. He had just been freed from the only teaching he had retained, that at the Sorbonne, and was about to give himself up entirely to research. Full of hopes and plans for the future, he left his friends; but he never reached home. Crossing a crowded thoroughfare, he was knocked down by a dray, and "blind matter, mother of life and of sorrow, destroyed the brain which understood and controlled it and loved it so well."

At home, in the house on the Boulevard Kellermann, the only cheerful sounds were the baby voices of Irene and Eve, and gradually these called to Mme Curie to take up the burden of her life again. She went back to the Sorbonne, to the laboratory filled with such sad and happy memories of her husband, took over the direction of the

Cours, and later was appointed titulary professor in his place. Her research work she carried on as before, but it had now a double significance; not only was it a search for truth for its own sake, but it was also the best memorial she could build to him. In 1910, assisted by M. Debierne, she isolated radium and determined its atomic weight, and in the same year she published her *Traité de Radioactivité*, the most complete and scholarly work on radium in existence. In 1911 she received the unique distinction of being again awarded the Nobel Prize. In this choice the Swedish Royal Academy showed itself more broad-minded than the French Institute, which in the same year voted against admitting Mme Curie as an Academician, since there was "an immutable tradition against the election of women, which it seemed eminently wise to respect." Shortly after the outbreak of the Great War, a Radium Institute was started in Paris and Mme Curie was placed at its head. In this time of crisis the French Government was not troubled by precedent, but appointed her, as the greatest authority on radium, to take supreme control of "all work in radiology" in their military hospitals.

Since the Curies first started on their quest of radio-active substances in pitchblende, a whole new branch of physics has developed. While they and their friends were working in France, Sir Ernest Rutherford, Frederick Soddy, and Sir William Ramsay in England, and Boltwood in America, were carrying on research work of the

first importance. The discovery of electrons had led to the idea that they, rather than atoms, might be "nature's units," and that out of them all material substances might be built up. The study of radium threw a direct light on this question, for it was observed that both electrons, called in this case β-particles, and also much heavier positively-charged particles, or α-rays[1], are products of its activity. In 1902 Rutherford and Soddy put forward the theory that the source of energy in radioactivity is the disintegration of atoms, and this theory has since been abundantly confirmed. Following up some experiments of Rutherford's which showed that the α-particles might *possibly* be helium, Ramsay and Soddy proved that helium *is* one of the products obtained from radium, and finally, by a series of exceedingly delicate and difficult operations, Rutherford proved that the α-particles are actually, as was predicted, charged atoms of helium.

Here, for the first time in the history of science, we have the fact established that, in nature, one kind of element is being produced from another. We are still far from the goal that the alchemists set themselves, of converting, at will, one element into another; for up to the present all man's efforts to control this spontaneous transformation have been in vain. This failure should not, however, be a cause for discouragement, but rather a stimulus to further effort. In every great advance in know-

[1] Radium also gives off γ-rays, similar to X-rays, but these need not be discussed here.

ledge, Soddy reminds us, man has been aware of natural sources of energy long before he has known how to use them. Prehistoric man, for instance, must "in natural conflagration have been made aware of the energy in fuel before he had learned how to liberate it at will." So we, in this twentieth century, are aware of the energy in radio-active substances, but do not yet know "how to liberate it at will."

During the dark years of 1914–1918, when both her native and adopted countries were alike devastated by war, Mme Curie would sometimes hearten her pupils by telling them that "it is the charm of physics that forlorn hopes are always coming off." The attempt to control radio-activity is, at present, a "forlorn hope"; but, with Mme Curie's example of patient toil and of the courage that refuses to accept defeat, who knows but that victory may yet be ours? And in this field, above all, victory is worth fighting for; it leaves no problem of the vanquished and takes mankind one step further in their mastery of the secrets of the universe.

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DARWIN AND WALLACE AND THE EVOLUTIONARY THEORY

> Great discoveries belong not so much to individuals as to humanity; they are less inspirations of genius than births of eras.
> E. L. YOUMANS.

> It is the soul that gives worth to science....Every scientific discovery is a personal attainment and a personal realisation.
> W. FEARON HALLIDAY.

THE power of appreciating things or points of view for their intrinsic value, quite apart from their use to ourselves, is, as a recent writer[1] has said, a sign of spiritual progress, and exists with difficulty where the struggle for life is hardest, whether it be the struggle with nature for bare existence or the struggle with fellow-men for success, money, or power. The value of any form of civilisation can be judged, to a great extent, by the opportunities it affords men of attaining to this high and disinterested attitude of mind which gives them courage to follow a train of thought or a course of action regardless of consequences to themselves.

The average man has not yet reached this level; for him the universe centres on himself, his race, and his world, and it is intolerable to him to have this view challenged. When Galileo announced, in his pugnacious way, that the earth goes round the sun, the average man, who till that moment had never doubted that his earth was the pivot of

[1] See Mr A. Clutton Brock's article on "Spirit and Matter" in *The Spirit*.

the heavens, did his best to stop Galileo's mouth for ever; his great discovery only lived because his age, like every age, possessed some men with minds ready to receive new truth and to uphold it till the habits of men's thoughts had adapted themselves to meet it. So, too, when Darwin, in his modest and patient manner, propounded the simple yet disturbing theory of Evolution, the support of men with this scientific love of truth for its own sake, and, in particular, the generous championship of Wallace, to whom the same explanation of the origin of species had occurred, protected the theory from the attacks of the outraged majority with such success that it is now woven into the fabric of the thought and language of the whole civilised world.

Without this sympathetic support, the man of genius is "a voice crying in the wilderness," and in this sense every great discovery can be said to belong to humanity rather than to an individual; yet the other aspect of the truth must not be forgotten, that it is also "a personal attainment and a personal realisation." As we read the lives of Darwin and Wallace, we feel, perhaps with special force, this personal aspect of their discovery, that they found not only a great law of nature, but themselves.

Charles Robert Darwin (1809–1882), born at "The Mount," Shrewsbury, on February 12th, 1809, was the second son and the fifth child of Dr Robert Waring Darwin and his wife Susannah, daughter of Josiah Wedgwood, the famous Staffordshire potter. The doctor's father, Erasmus

Darwin, was a well-known naturalist, but he himself had "no pretensions to being a man of science"; he had, however, keen powers of observation, a good judgment of character, and the ability to interest himself in the minor details of people's lives, and these qualities made him a successful doctor in the best and broadest sense, a man whose help is sought in trouble as well as in illness. Mrs Darwin had a "gentle and sympathetic nature," and it was a great loss to her young family when she died in 1817. At this time Charles was about 8, but he carried into his later life nothing more than a memory of "her death-bed, her black velvet gown, and her curiously constructed work-table." From her, however, he probably inherited his sweet disposition, while his powers of observation and his scientific bent came from the Darwins.

As a small boy Charles went with his sisters to a day-school; there he was easily out-distanced by his younger sister, Catherine, and seems to have tried to attract attention to himself by childish naughtiness rather than by the more laborious method of working hard at his lessons. He used at this period, he tells us in his autobiography, to invent deliberate falsehoods for the sake of creating a sensation. Even at this early age, his interest in the variability of plants, combined with this love of causing excitement, led him to tell another small boy that he "could produce different coloured polyanthuses and primroses by watering them with certain coloured fluids," which, he writes, "was of course a monstrous fable, and had never been

tried by me." On another occasion, he gathered fruit from the garden, hid it in the shrubbery, and rushed breathless to his father to announce that he had discovered a hoard of stolen fruit. Of course, as with all sensitive children, these falsehoods—particularly the one about watering the plants, perhaps because it did violence to his scientific conscience—lay heavily on his mind, and his father showed himself unusually wise in overcoming this tendency "not by making crimes of the fibs, but by making light of the discoveries."

Charles' passion for collecting and classifying was clearly innate, for, though neither his brother nor his sisters possessed this taste, by the time he was 8 years old he had collections of shells, coins, seals, eggs, and minerals, and was interested in the naming of plants. His sisters taught him to be humane and to take only one egg from a clutch; and he was all his life devoted to dogs, and remembered with distress an isolated occasion in his boyhood when his love of power had prompted him to beat a puppy.

In the summer of 1818, when he was nine and a half, Charles was sent as a boarder to Shrewsbury, but, the school being only a mile from his father's house, he could often run home between call-overs, and so had the advantages of both school and home life. A century ago the education at Shrewsbury was, of course, strictly classical and so was not calculated to bring out a boy whose abilities were markedly scientific. Charles worked, on the whole, conscientiously, but was considered by his masters

as "rather below the common standard in intellect," and on one occasion Dr Darwin, usually the kindest of men and the wisest of fathers, was provoked to exclaim "You care for nothing but shooting, dogs, and rat-catching, and you will be a disgrace to yourself and all your family."

Even during this time at Shrewsbury, however, there were some hopeful signs of future development; his tastes were strong and individual; where interested, he could pursue a subject with immense zeal, and he felt a "keen pleasure in understanding any complex subject or thing." The historical plays of Shakespeare appealed to him at this period and, to a lesser degree, the poetry of Thomson, Byron, and Scott; in later life this taste was unfortunately lost, but the aesthetic love of scenery, first felt during a riding tour on the borders of Wales in 1822, persisted much longer. Towards the end of his school-days the passion for shooting, already mentioned, developed, and remained strong until the pursuit of science became more engrossing than the pursuit of birds, and he relinquished his gun because he had discovered "that the pleasure of observing and reasoning was a much higher one than that of skill and sport."

The elder Darwin boy, Erasmus, was about 5 years senior to Charles, and was naturally something of a hero in his young brother's eyes. He too had a taste for science and, towards the end of Charles' school-days, fitted up a chemical laboratory in the tool-shed in the garden. Charles was, of course, delighted to act as his "lab.-boy," help-

ing to make all the common gases and many compounds, and he read such books as *The Chemical Catechism* by Henry and Parkes with eager interest. When his school-fellows got wind of this extraordinary hobby, they nicknamed him "Gas," while his head-master, Dr Butler, thought fit to rebuke him in public, on one occasion, for wasting his time on "such useless subjects."

These unusual tastes did not make him unpopular at school, because they were perfectly genuine. He was an affectionate boy and had many friends; and no doubt, although "Nature Study" had no place on the time-table of those days, there were other boys besides Charles Darwin who had discovered its fascination and shared his enthusiasm for collecting minerals and insects and for watching the habits of birds. One school-fellow lent him a copy of *The Wonders of the World*, and this book first roused in him the desire to travel, perhaps with the idea of verifying some of its remarkable statements, about the truth of which he and his friends had many animated discussions.

As it was clear that the school-work was doing Charles no good, his father very sensibly took him away young and sent him in October 1825, before he was 17, to Edinburgh University, where Erasmus was finishing his medical studies. Here again, unfortunately, the work provided did not stimulate Charles' brain; he found the lectures dull and thought reading a better way of getting up a subject; and, having discovered that his father would leave him enough to live on, he made no great

effort to qualify as a doctor. Before coming to Edinburgh, he had attended some of his father's poorer patients and had felt a keen interest in the work. But, though he did not shirk his hospital visits in Edinburgh, the sight of some of the cases there distressed him greatly; he only attended two bad operations and rushed out before the end, which is hardly surprising, since one was on a child and it was long before the days of chloroform. After a year Erasmus left Edinburgh, and Charles, thrown on his own resources, began to make friends with men of like tastes. Of these the one who perhaps had most influence on his future was Dr Grant, a man considerably his senior, who hid under a dry and formal manner much real scientific enthusiasm. Together they collected and dissected marine animals and had many talks on scientific subjects, in one of which a burst of warm praise from Dr Grant of Lamarck and his views on evolution, though at the time it seemed to make no special impression on Darwin, may have unconsciously turned his thoughts in the direction which led to his own exposition of the subject, years later, in his *Origin of Species*.

Two years at Edinburgh were enough to show that Charles had no taste for doctoring; his father therefore suggested that he should become a clergyman and, with this end in view, sent him up to Christ's College, Cambridge. This meant a return to his classical studies and, as far as his academic work was concerned, his time at Cambridge was as much wasted as his time at Edinburgh and at

school. His taste for shooting and hunting, too, got him into a sporting set and he spent much time riding across country and dining with them. In after years he felt that he ought to regret this, but could not manage to do so because, as he wrote, "my friends were very pleasant, and we were all in the highest of spirits."

These pleasant sporting gentlemen, however, were not the only people with whom Darwin became intimate at Cambridge. He would go for long walks with Whitley, afterwards Senior Wrangler, and learned from him to appreciate pictures, so that he could pick out the best at the Fitzwilliam Museum. Another friend of his was Herbert, also a high Wrangler, and through him he obtained the *entrée* to a musical circle, in which he acquired such a strong taste for music that the pleasure of hearing the anthem at King's College Chapel would send a shiver down his back.

At this period his passion for collecting, which he himself likened to that of a virtuoso or miser, expressed itself in the pursuit of beetles. One day, having two rare specimens, one in each hand, and seeing a third, he popped into his mouth his right-hand captive, which promptly ejected such a horrible fluid that he had to spit it out again and so lost specimen number two and specimen number three as well.

The strongest influence in Darwin's Cambridge life, however, and one which affected his whole career, was his friendship with Prof. Henslowe. All men interested in science, whether dons or

undergraduates, had a general invitation to meet once a week at the Professor's house, and there Darwin went regularly and soon became so intimate with his host that they took long walks together almost every day. Henslowe had a wide knowledge of many sciences, an excellent judgment, and a nature devoid of all pettiness; and undoubtedly this friendship kept alive in Darwin the scientific curiosity that his academic studies failed to satisfy. Among the many books Darwin read and discussed with Henslowe, two, Humboldt's *Personal Narrative* and Herschel's *Introduction to the Study of Natural Philosophy*, made a specially deep impression and aroused in him "a burning zeal to add even the most humble contribution to the noble structure of Natural Science." Henslowe encouraged Darwin to study geology, and procured for him on leaving Cambridge in 1831 an invitation to accompany Prof. Sedgwick on an excursion into North Wales. At this time geologists had not realised the existence of a glacial epoch on these islands, and, years afterwards, Darwin commented with amazement on the fact that, while working in the valley of Cwm Idwal, strewn with "plainly scored rocks, perched boulders and lateral and terminal moraines," neither of them saw a trace of these signs of glacial action, although "a house burnt down by fire did not tell its story more plainly than did that valley."

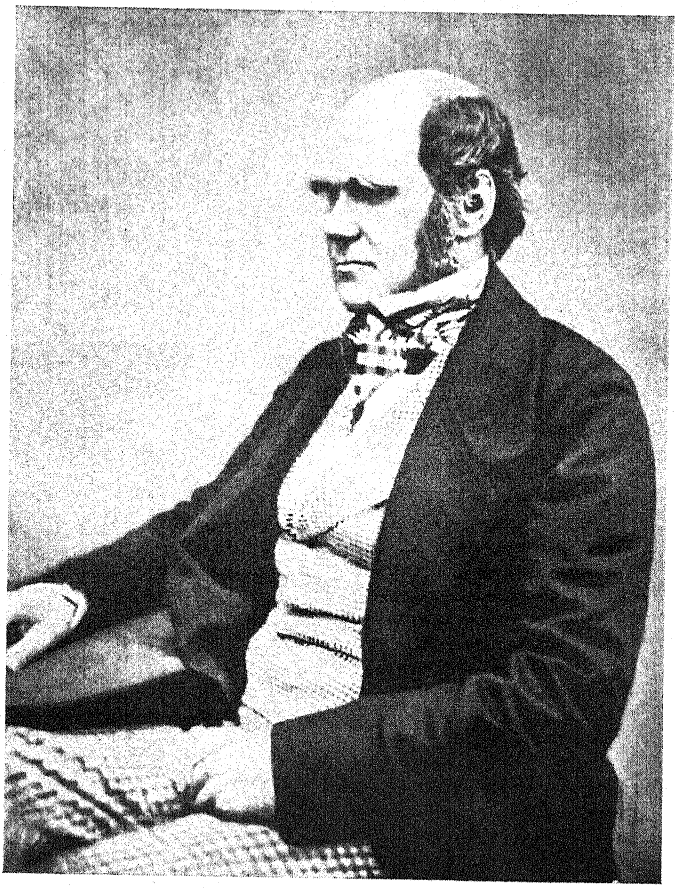
On his return home from this tour, Darwin found awaiting him a letter from Henslowe, containing an invitation to go without pay as naturalist

on the little barque *Beagle*, which was about to set out on a voyage "to complete the Survey of Patagonia and Tierra del Fuego, to survey the shores of Chili, Peru, and some islands in the Pacific; and to carry a chain of chronometrical measurements round the world." Darwin was eager to accept; his father objected, but added, "If you can find any man of common-sense who advises you to go, I will give my consent." This proviso was fortunate, for Charles' uncle, Josiah Wedgwood, strongly advised him to go, and Dr Darwin therefore withdrew his opposition. The next difficulty, as Darwin heard afterwards, was the shape of his nose, which the eccentric captain of the *Beagle*, Fitz-Roy by name, feared indicated a lack of energy and determination; but luckily this did not turn the scale against him and he was duly appointed naturalist for the voyage. This voyage lasted for nearly five years, from December 1831 to October 1836, and a full account of his work during this period is given by Darwin in his *Journal of Researches during the Voyage of the Beagle*. Here only the general effect of it on his character and later life can be mentioned. Undoubtedly it was, in many senses, the turning-point of his career. He collected animals from the sea and from all places at which their vessel touched, observed carefully the geology as well as the natural history of each district, and each day wrote his journal, taking pains to describe "carefully and vividly" all that he had seen. There had been some ground for Dr Darwin's uneasiness lest

Charles should be content to settle down as a mere sporting gentleman, but this work saved him; through it he acquired a "habit of energetic industry and of concentrated attention," and, though at first he enjoyed shooting his own specimens, he gradually gave up his gun more and more to his servant, as his passion for science grew stronger than his passion for sport. Besides this, the vast mass of facts recorded so accurately in the *Journal* established his reputation as a distinguished naturalist and, even more important, supplied him with material for his own great contribution to scientific thought.

On his return home in October 1836, Darwin took lodgings for three months in Cambridge, where his collections were in Henslowe's care, and then in Great Marlborough Street in London, where he remained till his marriage in January 1839. He spent this time in preparing, from the material he had collected on the voyage, a *Journal of Travels*, a book of *Geological Observations*, and one on *The Zoology of the Voyage of the Beagle*. He had read during the voyage the first volume of Lyell's *Principles of Geology*, and had been much impressed by his method of treatment of the subject; he was therefore delighted to find, on meeting Lyell on his return, that his own views and the facts he had collected were received with sympathetic interest by the more experienced geologist. This interest encouraged Darwin greatly, and Lyell's friendship and advice were from this time onwards important factors in his life.

Darwin's marriage with his cousin, Emma Wedgwood, was, like Faraday's, a happy one, and his wife's devotion and care rendered possible a life of hard work in the teeth of continual ill-health. For, from 1839 onwards, Darwin, always wiry rather than strong, became a partial invalid. At first they lived in a small London house, No. 12 Upper Gower Street; but, finding that the excitements of social life, which Darwin much enjoyed, invariably brought on attacks of sickness, they retired into the country in 1842 and spent the rest of their married life in a pleasant house at Down in Surrey. Here, by following a careful routine, Darwin was able to keep sufficiently well to work on most days at his absorbing scientific pursuits. The mornings being his best time, he got up early and took a turn before breakfast, sometimes accompanied by a small son, listening perhaps to tales of foxes seen trotting home at dawn; at 7.45 he breakfasted alone, and afterwards worked from about 8 to 9.30. At 9.30 he looked at his letters and then lay on the drawing-room sofa listening to the reading aloud of family letters and usually part of a novel till 10.30, when he went back to work in his study again till 12 or 12.15. After this, calling to his favourite dog, he would go out, wet or fine, for a constitutional, and the children, playing on a strip of land called the "sand-walk," would see him walking—at first with a swinging and then with a flagging step—round the gravel path that circled it, and would call to him to come and see what they were doing and to sympathise with any



CHARLES ROBERT DARWIN

fun that was going on. After lunch he read the paper, lying on the sofa, and then answered his letters, even those from the most inconsiderate correspondents, with scrupulous care; from 4 to 4.30 he went for another walk and from 4.30 to 5.30 again did some scientific work, but otherwise the afternoon and evening were spent lying down, while his wife, or, later, a son or daughter, read to him. When resting he often smoked a cigarette, but found snuff a stimulant to work; when interested, particularly if dictating, he would dash into the hall for a pinch of snuff, calling out the end of his sentence as he went.

This was, for forty years, the daily life of Charles Darwin and these the conditions under which he had to work. He owed much, as he himself thankfully acknowledged, to the fact that his independent means freed him from the necessity of earning his living in some uncongenial manner; much too—more than can be expressed—to his wife's devoted care; yet, allowing for all this, he still stands out a gallant figure, working to the limit of his strength and refusing to yield to the peevish invalidism into which it would have been so easy to sink.

Many years of this time were devoted to some detail of biological or geological interest and embodied in such books as *Coral Reefs*, *The Fertilisation of Orchids*, *The Formation of Vegetable Mould through the Action of Worms*; but this task, valuable in itself, is quite overshadowed by the twenty years of patient research devoted to his theory of the origin of species.

In the middle of the nineteenth century it was generally held that each species arose by an act of "special creation" and that fossils had been produced in the same way, "with a false resemblance to living things." Darwin, on his voyage on the *Beagle*, had been greatly impressed by the similarity between fossil and extant animals and also by the fact that the flora and fauna on the islands of a group differ slightly from island to island, and he was by no means satisfied with the accepted explanation. At what moment his own theory began to form in his mind we do not know, but when, on July 1st, 1837, he opened his first notebook for facts bearing on the origin of species, he tells us that he had long reflected on the subject. Fifteen months later his ideas crystallised, as he writes, in the following way:

> I happened to read for amusement Malthus on "Population" and being well prepared to appreciate the struggle for existence which everywhere goes on from long-continued observation of the habits of animals and plants, it at once struck me that under these circumstances favourable variations would tend to be preserved, and unfavourable ones to be destroyed. The result of this would be the formation of a new species. Here, then, I had at last got a theory by which to work, but I was so anxious to avoid prejudice that I determined not for some time to write even the briefest sketch of it.

That quotation gives, in a nut-shell, the secret of Darwin's deserved success—"long-continued observation," an inspiration, held in severe check "to avoid prejudice," and again long-continued

observation, until the facts and the theory are proved to fit each other so perfectly that they may be given to the world.

In June 1842 Darwin first "allowed himself the satisfaction" of writing a short abstract of his theory; in 1844 he slightly enlarged this; and in 1856 he began, on the advice of Lyell, to write out his views pretty fully for publication in book form. This work was only half finished by 1858, when the receipt of a little paper from the Malay Archipelago threatened to take from him the right to publish the book as embodying—as in fact it did—his own original views on the problem of the origin of species. For the paper, written by Alfred Russel Wallace, was a short and clear exposition of the identical theory that Darwin's book was to establish. What did Darwin do next? Here was a test for the generosity of a scientist. Were twenty years of research to count for nothing? These questions must wait for answers while we turn back and trace the steps by which Wallace, working quite independently, had arrived at the same conclusion as Darwin at almost the same time.

The circumstances and upbringing of Alfred Russel Wallace (1823–1913) were, in the narrow worldly sense, less "fortunate" than those of Charles Darwin. His father, Thomas Vere Wallace, had been called to the Bar, but, coming into an income of £500 a year, never practised, and lived when a bachelor with happy carelessness, though without real extravagance, up to his means. On his marriage in 1807 with Mary Anne Greenell, of

Hertford, he took a house in Marylebone, and, soon finding his income too small for the expenses of a house, a wife, and a steadily increasing family of children, he rashly embarked on an effort to supplement it by the launching of a new illustrated magazine, "devoted apparently to art, antiquities, and general literature." This and a subsequent venture of the same nature proved failures and seriously reduced, instead of adding to, his already inadequate means. By 1818 his finances were in such a state that he decided to move with his wife and six children to some place where living was cheaper than in London; a "roomy cottage with a large garden" was secured at Usk in Monmouthshire, and there, on January 8th, 1823, Alfred Russel Wallace was born. Five years later the family left Usk for Hertford, lived there for nine or ten years, and then moved to Hoddesdon, where in 1843 Thomas Vere Wallace died at the age of 72. During the last fifteen years of his life his money affairs went from bad to worse, not from any serious fault of his own but rather from over-confidence in his own schemes and in the ability and good faith of his friends. The children had to earn their own living as soon as possible and life was for many years one long struggle to make ends meet; but their characters suffered little from this strain, since their father's inability to earn a livelihood was largely redeemed by the real interest he took in them and their mental development.

After a brief time at a little school in Essex, Alfred was sent to the Grammar School at Hert-

ford and remained there till he was fourteen. The dreary notion, then in vogue, that education consists in drilling facts into the heads of the young, pervaded the teaching at this school and successfully stifled for Wallace all interest even in geography, to which subject he made such valuable contributions later, so that he ranked it next to Latin grammar among distasteful subjects; and the only lessons he remembered with real pleasure were those in which the Headmaster read verse translations of Virgil.

Like Darwin, Wallace gained little from his school-days, and the development of his mind during his boyhood was largely due to his wide general reading, which his father's love of books and interest in his children did much to encourage. Thomas Wallace would get hold of books of travel and biographies through reading clubs or lending libraries and read them aloud to the family in the evenings, and, when Bowdler's edition of Shakespeare came out, he bought it and read many of the best plays to his children.

The eldest brother, William, had had a reasonably good professional education as a surveyor and, when Alfred left school, undertook to arrange for his apprenticeship in land-surveying. Before these arrangements were complete, however, the family had to move to Hoddesdon, and Alfred was therefore sent, in order to be out of the way, to live for a short time with Mr Webster, a builder in North London, to whom his brother John, about five years his senior, was already apprenticed. Having

no definite work, Alfred was free to follow his own inclinations and spent most of the day reading or among the men in the work-shop and the evenings with his brother at a working-men's club called "The Hall of Science." The men who met here were mainly followers of Robert Owen, and the ordinary life of the club—the reading of papers and books, the playing of games and drinking of coffee—was enlivened by keen discussions on social problems. Alfred, fresh from school, watching the workmen in the shop by day and listening to the eager talk at night, conceived a great admiration for Owen and a hatred of the social and industrial evils that he sought to combat, and these early first-hand impressions undoubtedly added fire and conviction to his reasoned indictment, years later, in *The Revolt of Democracy* and other books, of the injustices and confusion of the industrial system.

In the summer of 1837, after a few months in London, Alfred joined his brother William at Barton in Bedfordshire as an apprentice in land-surveying. This work involved the study of trigonometry and practice in taking observations, which afterwards proved invaluable for his geographical work in uncharted lands, while, in the out-door country life, he began to feel both the aesthetic and scientific appeal of nature, so that he wrote verses on her charms and longed to know how to classify flowers and plants. In 1838, no chance of further surveying work opening for him at the moment, Alfred was sent to Mr Matthews, a

watch-maker at Leighton Buzzard, to learn watch and clock-making as well as general engineering. He was comfortable enough with Mr and Mrs Matthews, who were pleasant people, and he might easily have settled down for life to the business of watch-making if a change in Mr Matthews' plans had not, fortunately for Alfred, thrown him out of work and so set him free to return to his brother William and to the work of surveying. At this time land was being enclosed in accordance with the General Enclosure Act, and the two Wallaces obtained work in connection with the enclosure of common lands near Llandrindod Wells. The working of this Act involved much hardship to smallholders and cottagers by depriving them of ancient grazing and other rights, and Alfred, observing these effects for himself, was deeply impressed, although at the time no solution of the land question entered his head. Writing later of his feelings at the time, he says "I certainly thought it a pity to enclose a wild, picturesque, boggy, and barren moor; but I took it for granted that there was some right or reason in it instead of being, as it certainly was, both unjust, unwise, and cruel." This first-hand experience, before he was twenty, of the oppression of the country poor, however, set him thinking on the land question, just as his direct contact with town workmen as a boy had set him thinking on industrial problems; and this thought bore fruit years later in his ardent championship of the nationalisation of the land.

In 1841 Wallace and his brother got work near

Neath, and, as Alfred's share of the work was slight, he had plenty of time to himself and began to study science systematically. A book on nautical astronomy taught him to make calculations which afterwards helped him greatly in his explorations, and another on systematic botany enabled him to name "the charming little eyebright, the strange looking cow-wheat and lousewort, the handsome mullein and the pretty little creeping toadflax, and to find that all of them as well as the lordly fox-glove formed part of one great natural order." "This," he wrote later, "was the turning-point of my life, the tide that carried me on not to fortune but to whatever reputation I have acquired, and which has certainly been to me a never-failing source of much health of body and supreme mental enjoyment."

When, in 1844, Wallace came of age, he had to leave Neath, as no surveying work was forthcoming at the moment, and he took a post in the Leicester Collegiate School. Here, besides teaching the "three R's" to young boys and surveying and drawing to a few older ones, he studied higher mathematics with the Headmaster, read a good deal of history, and became interested in psychical research. He also began a collection of beetles, made the acquaintance of the naturalist, H. W. Bates, and read Malthus' *Principles of Population*. This book is mentioned because what Wallace called the "revolting ratios," by which Malthus showed the alarming rate at which, in theory, mankind might increase, drew his attention to facts

which, when applied to the animal kingdom as a whole, led him to discover the process which Darwin called "Natural Selection." As in Darwin's case also, his passion for collecting beetles was peculiarly fortunate, as beetles illustrate with great clearness the action of this process in one particular group.

The unexpected death of his brother William in 1846 recalled Wallace to Neath, and there, having settled his brother's affairs, he was able to get, thanks to the new railway craze, profitable levelling work in connection with a proposed line from Neath to Merthyr Tydfil. Here his brother John, giving up his work in London, joined him shortly afterwards for the purpose of starting with him a building and engineering business. This venture was, in a modest way, quite successful; but Wallace found business life uncongenial and became more and more anxious to exchange it for that of a naturalist. He and Bates had kept up a correspondence, chiefly about their collections, and out of this arose a plan for an expedition to collect specimens in the tropics, if there were any likelihood of paying their expenses by the sale of their collections. Mr W. H. Edwards' book on *A Voyage up the Amazon* decided them to choose Para and the Amazon, and, being assured by an expert at the British Museum that the price of their collections would be likely to pay for the tour, they made all arrangements and set sail for South America on April 20th, 1848. A full account of this romantic and adventurous expedition, which

lasted four years, is given by Wallace in his *Travels on the Amazon and Rio Negro*; much of the time they were in unexplored land, quite out of touch with civilisation, and their geographical surveys and collections were invaluable. Most unfortunately, however, shipwreck destroyed the greater part of these unique collections, so that, on his return home, Wallace had only a few specimens, sent home earlier, left to describe. This done and his book on the Amazon finished, he began to prepare for further explorations in the East, and set sail in 1854 for the Malay Archipelago.

There, during an attack of fever in 1857, the idea of "the survival of the fittest," that had dawned on Darwin's mind nearly twenty years before, came to him in a flash of inspiration; as he lay in bed, the vast mass of facts with which his mind was stored fell into their places and he could hardly wait for his fever to subside before getting his thoughts down on paper. He had read Darwin's *Journal* some years earlier and, through it, had been so much attracted to the writer that, though at this time he had only met him once casually in the British Museum, he decided to send his paper to him with the request that, "if he thought it sufficiently important, he would show it to Sir Charles Lyell."

Darwin would have been more than human if the arrival of this paper had not caused him a pang of keen personal disappointment, but this did not affect his action; he decided to publish Wallace's views at once. Fortunately, however, Lyell and

Hooker, with whom he had discussed his theory years before, insisted that, when the paper appeared, an abstract from Darwin's own MS. should be published at the same time, and, a reluctant consent being obtained from Darwin, the two contributions were read on July 11th, 1858, before the Linnean Society. These papers attracted little attention and Darwin therefore decided to continue his book, making it shorter than at first intended, but long enough to press home the new view by examples and arguments. This method of treatment meant drastic weeding and selecting from the vast mass of material he had collected, but had the advantage of putting the theory in a compact and readable form supported by the most striking examples, while objections and apparent exceptions to its application were conscientiously noted. Darwin's self-restraint and fair-minded presentation of his views had its reward, for, when the book appeared in November 1859 under the title of *The Origin of Species*, it had an immediate and amazing success.

In 1862 Wallace returned to England to find both himself and Darwin famous and the views they shared discussed, either with approval or censure, on every hand. Nothing brings out more clearly the fineness of these two men than the fact that their common discovery resulted not, as so often happens, in a jealous pushing for the first place, but in a generous rivalry each to give the other his due. In some details they differed widely in their exposition of the Evolutionary Theory, but

this never affected their personal relations, which from this time till Darwin's death in 1882 remained one of warm friendship. Wallace lived on till 1913, and a whole book could be written on his many-sided activities; but looking at both him and Darwin primarily as scientists, this is the climax of their achievement, and the interest in their individualities is merged in the interest in the theory that united and made them both great.

In the region of speculative thought the idea of the evolution of higher organisms from more lowly is not new; it dates back at least to the Greek philosophers, its influence is shown in the writings of some of the Church Fathers, and it was advanced with renewed vigour at the end of the eighteenth century, in England by Dr Erasmus Darwin, the grandfather of Charles Darwin, and in France by such men as Lamarck and Buffon. The early philosophers, however, had not learnt the need for submitting theory to the test of fact, and Lamarck and the eighteenth century Evolutionists, in their reaction against the mere classification which contented Linnaeus and others, were nothing but theorists also, and based their argument on the belief, quite unsupported by evidence, that characteristics acquired during the life-time of an organism can be passed on to its progeny and, in this way, divergences in various directions from a common ancestor be produced. The absence of evidence to support this theory prevented it from being generally accepted, and for the next fifty years naturalists concentrated on the collection of

data, with the result that by the middle of the nineteenth century, as Darwin said, "innumerable well-observed facts" were stored in their minds, "ready to take their places as soon as any theory which would receive them was sufficiently explained."

These facts, collected by Darwin and Wallace and their fellow-naturalists, showed that the earth is peopled with an immense diversity of animals and plants, which, though varying individually, yet are grouped in definite species which in a given habitat vary very little, while in slightly different environments, as on neighbouring islands, these species have local peculiarities to which they "breed true." This conformity to type in a wild state is in marked contrast to the tremendous changes wrought in quite a short time under domestication. What accounts for this difference? Now, all organisms produce many more offspring than can survive, and these, whether in the wild or domesticated state, are not all alike, differing in greater or less degree from their parents and from each other. Under domestication, man selects those to survive and breed which have traits useful or pleasing to him, and so produces, in a comparatively short time, such widely different types as cart-horses and race-horses or greyhounds and bulldogs from the same parent stock. Is there any process in nature corresponding to man's choice which would serve, in certain conditions, to keep a species constant and, in certain others, to produce new species from it? Darwin observed that in a

wild state, if the conditions remain unchanged, the members of a species tend to cross freely and therefore "any tendency in them to vary will be constantly counteracted"; while, if the conditions alter, only those individuals whose idiosyncrasies fit them for their changed environment are likely to survive and have offspring. If the climate becomes colder, the cubs of a litter who have the thickest coats are more likely to live than their less warmly clothed brothers; if huntsmen become more skilled, the cunning fox has a better chance of escape than the less resourceful one; and if hen-birds develop their taste for gay colours, and does for mates who have come through the ordeal by battle, the gaudiest cock and the unbeaten stag will breed where the dowdier bird and the less valiant stag will be slighted or slain. The process which these examples illustrate Darwin called "Natural Selection," and maintained that by its means all existing species have arisen from a few parent forms, just as, by man's selection, the vast number of domestic races have been produced from a few wild types. This argument falls to the ground unless conditions on the surface of the earth have changed periodically, and so have caused both the elimination of some species only suited to the old environment and the evolution from them of new species adapted to the new environment. Is there any evidence that this has taken place? Here Darwin's geological knowledge supplied the answer, for the work of such men as Lyell proved that conditions on the earth's surface *have* varied

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enormously throughout the ages, while the classification of fossils showed that they are arranged in groups falling not *in* but *between* the corresponding classes of living forms, which is just what would be expected if they are, what they seem, petrified relics of the life of the past.

This, in brief, is the theory contained in the paper sent home by Wallace from the Malay Archipelago and developed, with the support of numerous carefully verified facts, by Darwin in *The Origin of Species*. Darwin's strength lay, as Wallace gladly acknowledged, in his "untiring patience in accumulating," and his "wonderful skill in using, large masses of facts of the most varied kind," and his book, "written in an admirable style of composition, at once clear, persuasive and judicial," established beyond dispute the fact of Evolution; but Wallace's contribution was hardly less important, for, in certain directions where he differed from Darwin, he developed the theory along sounder lines.

Only the two most serious lines of attack on the doctrine of Evolution can be mentioned here, that which is based on Darwin's mistaken views on the causes of variation and that which arises through a supposed contradiction between the Christian and Evolutionary philosophies.

The recent tendency to discredit the Evolutionary Theory has arisen mainly through the fact that Darwin regarded change of environment as the chief cause of variation, while modern investigators lay all the stress on heredity. Now this opinion of Darwin's is not an essential part of the conception

of Natural Selection, as is shown by the fact that Wallace did not share it. In his early paper, Wallace suggested no cause for the observed fact of variation and, when Weismann challenged the old belief in the inheritance of acquired characteristics and proved that "organisms have an inherent tendency to vary," Wallace welcomed the new view. In our own time much patient and valuable work is being done by Prof. Bateson and others on the causes of variation and the laws of heredity, but the interest and importance attaching to these researches should not blind us to the greatness of Darwin's discovery. Rightly regarded, the present study of the factors governing inheritance is supplementary rather than antagonistic to the work of the early evolutionists, for selection, whether by man or by nature, can only act on variations as they appear. Any insight, therefore, into the causes of variations throws fresh light also on the problem of the origin of species, while leaving untouched the theory, put forward by Darwin and Wallace, as to how nature deals with these variations after they have arisen.

This modern attack comes from men of science and is based on an alleged incompatibility between recent discoveries and evolutionary teaching. The contemporary opposition, which persists even now in certain church circles, was both more widespread and less well-informed. It appeared, at first sight, as if the doctrine of Evolution was opposed to the teachings of religion, for it cut at the roots of man's belief in the beneficent interference of

the Creator in acts of "special creation" and, further, shook his confidence in the uniqueness of his own position in nature. A little more thought and study, however, reveal the fact that the method of creating the myriad forms of the material world, which Darwin called Natural Selection, is actually more in keeping with what we know of the workings of the Divine Mind than the method of special creation. This Darwin himself clearly brings out in the closing paragraphs of *The Origin of Species*:

> To my mind it accords better with what we know of the laws impressed on matter by the Creator, that the production and extinction of the past and present inhabitants of the world should have been due to secondary causes, like those determining the birth and death of the individual. When I view all beings not as special creations, but as the lineal descendants of some few beings which lived long before the first bed of the Cambrian system was deposited, they seem to me to become ennobled.... Thus, from the war of nature, from famine and death, the most exalted objects which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and wonderful have been, and are being, evolved.

This is the voice of the naturalist at his highest, but, to answer man's questionings about his own destiny, something more is needed; he conceives an even more exalted object than the production of the higher animals—the production of the ideal

man. This need Wallace, with his broad human sympathies, felt in a way that Darwin, the recluse, could not do, and his views on this subject show a correspondingly deeper insight:

"On this great problem," he writes, "the belief and teaching of Darwin was, that man's whole nature—physical, mental, intellectual, and moral—was developed from the lower animals by means of the same laws of variation and survival; and, as a consequence of this belief, that there was no difference in *kind* between man's nature and animal nature, but only one of degree. My view, on the other hand, was, and is, that there is a difference in kind, intellectually and morally, between man and other animals; and that while his body was undoubtedly developed by the continuous modification of some ancestral animal form, some different agency, analogous to that which first produced organic *life*, and then originated *consciousness*, came into play in order to develope the higher intellectual and spiritual nature of man."

Surely this view accords with the deepest needs and the highest hopes of mankind. Because we are animals it does not follow that we are nothing more than animals. A sheep slipping over the edge of a cliff falls to the bottom at the same rate as the stone it dislodged. It obeys the same law of gravity as the lifeless stone, but is it therefore no more than a stone? Man feeds as an animal and reproduces as an animal, but is he therefore no more than an animal? A child learning to toddle is being taught how to use the laws of gravity constructively; a boy learning to feed wisely and temperately is training himself for more than the race he hopes to win, and the man who has discovered how to

manage his body both as a lump of insensate matter and as a sensitive living organism is best fitted to express himself intellectually and spiritually as well. The art of living is the art of learning how to use the laws that govern our being at each level so that they help rather than hinder us in our effort to reach the heights of which our natures are capable.

> Does the fish soar to find the ocean,
> The eagle plunge to find the air—
> That we ask of the stars in motion
> If they have rumour of thee there?

Do not these words of Francis Thompson reconcile the Christian and the Evolutionary philosophy, in the faith that only by accepting humbly the limitations of our human life can we rise above them to the stars?

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My Life, by Alfred Russel Wallace.
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PASTEUR AND HIS WORK ON GERMS AND INOCULATIONS

Life in the midst of danger is *the* life, the real life, the life of sacrifice, of example, of fruitfulness. PASTEUR.

NATIONS and individuals can be judged largely by their heroes. Primitive people and children look up to the giant-killer, the slayer of dragons, the "strong man" who forms great empires and rules them with a rod of iron. Older and more civilised people look deeper for their admirations; their heroes fight for ideals against ideas, and though the enemy often eludes them and doubt assails them, their failure is nobler than the "strong man's" success.

The struggle with nature, which we call the progress of science, has followed much the same course as man's developing sense of the truly heroic. At first his struggle was with gigantic forces, great beasts, mighty waters, impassable mountains, heat and cold. When these were mastered, he began to look closer and deeper, and the closer and deeper he looked, the more clearly he saw that mere size is nothing, that every particle of matter and every living organism is important only for what it *is* and for what it *does*.

The work of some scientists resembles that of the farmer; they search into nature's secrets that they may use them to add to the fulness of man's life. The work of others is like that of a General Headquarters Staff; they set themselves the grimmer

task of discovering the workings of nature that they may fight her. The two types of work are only apparently opposites: Priestley saw in the invisible air life-giving oxygen; Pasteur saw in it the germs of disease and death; yet both men were inspired by the same desire to enrich and to save human life.

The early life and family circumstances of Louis Pasteur (1822–1895) were, in some respects, not unlike Faraday's. The Pasteurs were simple stay-at-home country folk. The name can be found in old registers in the province of Franche Comté as far back as the early seventeenth century. A generation or two before Louis' birth the family took to tanning; and this was the business of his father, Jean Joseph, though, before settling down to his trade, he had a brief interlude of more stirring life, fighting from 1811 to 1814 on the battlefields of Europe. He was a member of the valiant 3rd Regiment, called "brave among the brave," and earned with many others the cross of the Legion of Honour. In later years he painted on an inner door of his house a soldier in an old uniform pausing in his digging to lean on his spade and dream of past glories. He was as a rule "reserved, almost secretive," not at all the typical old soldier who frequents cafés to talk of his campaigns; but it is hard to believe that there were never moments when his little son could tease from him stories about the sword on the wall and the painting on the door.

Louis' mother, Jeanne Etiennette Roqui, came

of a family of gardeners. Joseph, looking up from his work at the tannery in the early mornings, used to see her working in the garden across the river. The Roquis were an old though humble stock, people of hard-working traditions and of such warm affections that "to love like the Roquis" was a local saying. Jeanne was "active, full of imagination and ready enthusiasm," a complete contrast to Joseph with his "slow and careful mind apparently absorbed in his own inner life." What more natural than that they should attract each other? In 1815 they were married, and throughout their life together they created an atmosphere of happiness and devotion to high ideals that gave a meaning to their daily toil and—as it always will do—made a lasting impression on their children. Their first child died; then, in 1818, a girl was born; next Louis, at Dôle, on December 27th, 1822, and later two more daughters.

Boys with scientific enthusiasms, who yet fail to distinguish themselves at school, may be encouraged to know that Pasteur was by no means the ordinary "clever boy" who has such an annoying habit of slipping past everyone to the top of the form without apparent effort. During his school-days the family lived at Arbois, and he attended first the "Ecole Primaire" attached to Arbois College, and then the College itself; and there, though he won several prizes, the general impression was that he was merely "a good average pupil" and on the whole rather slow. M. Romanet, the Head, however, was a man who looked below the

surface and saw that all slowness is not due to the same cause; Louis Pasteur, for instance, seemed slow because his mind worked carefully and "he never affirmed anything of which he was not absolutely sure." Romanet would stroll round the playground drawing the boy out, and it was he who first fired him with a desire to go to the "Ecole Normale" and so prepare himself to become a "professor," as schoolmasters are called in France[1].

Two family friends also made a great impression on Louis at this time, Dr Dumont, an old army doctor, who combined a life of study with a practical life of doing "a great deal of good while avoiding popularity," and Bousson de Mairet, a great reader and student of the characteristics of the Arboisians. The former's influence strengthened Louis' admiration of a life of hard work for the good of others, and the latter's inspired him to read of the brave deeds of his own people and fired him with a local patriotism which widened later into his deep love of France herself. Books and day-dreams, however, were not Louis' only interests. He was fond of drawing and several portraits done during his school-days show considerable talent; his friends called him an artist, but this only half pleased his father, who was anxious about the boy's

[1] The "Ecole Normale Supérieure" was a training college. Candidates must be between the ages of eighteen and twenty-one and be already Bachelors of Science or of Letters. There are degrees above the "Baccalauréat" in France, "Licence" and "Doctorat," and the standard for the bachelor's degree is considerably below the standard for a B.A. or B.Sc. at an English University.

future and could not see where his preference for drawing would lead him. In the holidays he led an ordinary boy's exuberant out-door life; he was as ready as anyone to answer to the shouts of his school-fellows to come out and play. His special friend, Jules Vercel, was a great fisherman and Louis watched his net-throwing with admiration; bird-trapping, however, he avoided, for he could not bear the sight of the poor wounded larks.

The question of the Ecole Normale, always in the background of Louis' thoughts, became a practical one when he was fifteen, for an opportunity arose for him to go to Paris to work for his "baccalauréat." A certain M. Barbet, a Franc-Comtois, had a school in the Latin Quarter and was ready to take Louis, as he had taken other boys from his own district, at reduced fees. Joseph Pasteur thought the boy too young to send so far from home, but Jules Vercel was going to Paris for the same purpose and so it was finally decided that the boys should go together. Is home-sickness worse when you have expected it or when it comes upon you without warning? Poor Louis, setting off for Paris with eager hopes, was met there by Giant Despair. Few people would choose to live near a tan-yard, but to Louis all the scents and sights of Paris could not make up for the lack of its familiar odour. "If I could only get a whiff of the tannery yard," he would say to Jules Vercel, "I feel I should be cured." Louis fought his weakness, M. Barbet and Jules did what they could, but his grief was too deep to be reasoned away and, after a

month's struggle, it was thought wiser for his father to come and take him home.

Now there was nothing for it but Arbois College again. The effects of Paris on Louis had naturally frightened his father, and hopes of the Ecole Normale, and of a wider life than Arbois could offer, must be put aside. Once recovered from his home-sickness, Louis settled down to school-work again; but still the Ecole Normale and all it stood for kept thrusting itself into his thoughts. At the end of the year 1839, he persuaded his father to agree to a very sensible compromise, that he should go to the college at Besançon—only 25 miles from home—and there pass his "baccalauréat" and prepare for the Ecole Normale. This arrangement worked well, and in January 1841 he was considered responsible enough to be made a supplementary master, which involved superintending the preparation of his fellow-students. For this work, as he boasted proudly to his parents, he received, besides his board and lodging, 300 francs (about £12) a year! He was now eighteen and his position and responsibilities were very much those of a school praepostor. His letters show how seriously he took his work and life generally and, at the same time, are full of love and thought for the home circle. "Dear Sisters," he writes, "work hard, love each other. When one is accustomed to work it is impossible to do without it; besides, everything in this world depends on that."

At another time he wants to pay for the schooling of one of the little girls, saying that he can easily

do it by giving private lessons. This he had already been asked to do at the rate of 20 to 25 francs a month, but had refused because he had little enough time for his own work. His parents would not hear of his making this sacrifice, but wanted instead to give him a small allowance for extra coaching for himself.

Early manhood is the time for making friends, and Pasteur found one after his own heart in Charles Chappuis, a "philosophie" student and the son of a country notary at Besançon. Chappuis' father was a man whose round of simple duties was dignified by the spirit in which it was done, and from him his son had learned, even as Louis Pasteur had learned from his father, to face life with a proper sense of values. These two opened their hearts and minds to each other and mapped out the future together.

In 1841 Chappuis went to Paris to prepare for the Ecole Normale, and a year later Pasteur returned to the Barbet boarding school as part master and part pupil, paying one-third pupil's fees and in return teaching mathematics to younger boys from 6 to 7 in the morning.

"Do not be anxious about my health and work," he writes home, "I need hardly get up till 5.45; you see it is not so very early....I shall spend my Thursdays in a neighbouring library with Chappuis, who has four hours to himself on that day. On Sundays we shall walk and work together; we hope to do some philosophy on Sundays, perhaps too on Thursdays; I shall also read some literary works.

Surely you must see that I am not home-sick this time."

In 1842 Pasteur had been examined for a degree in science but had not taken a good place, being only "moderate" in chemistry and low on the list for the Ecole Normale. This determined him to read more and to offer himself again for examination, and with this end in view he attended Dumas' lectures at the Sorbonne. "You can imagine," he wrote home, "what a crowd of people come to these lectures. The room is immense, and always quite full. We have to be there half an hour before the time, to get a good place, as you would in a theatre; there is also a great deal of applause, there are always six or seven hundred people."

Dumas, like Faraday, had the secret of opening, as he lectured, "boundless horizons before every mind"; what wonder that Pasteur's vivid imagination caught fire? At Besançon he had got as far as steady hard work would take him; but now at Paris he worked with fresh inspiration, and the result was that, when he was examined again in the summer of 1843, he did well and was placed fourth on the list for the Ecole Normale.

The Ecole Normale at last! What did it not mean to him? Lectures, books, experiments, ideas crowded one another out—hardly time even for walks with his beloved friend. Look at him now engrossed in an experiment, Chappuis waiting patiently on a laboratory stool till at last Pasteur throws off his apron and says half angrily and half gratefully, "Well, let us go for a walk." And, when

they get out, what do they talk about? Experiments, lectures, reading, and all the thoughts these send surging through Pasteur's brain. Fortunately Pasteur was a vivid talker, and Chappuis, by taste a philosopher, would listen not only with patient but with eager attention and his questions would often help his friend to get his thoughts clear.

The period 1844 to 1847 was devoted to chemistry; no special events stand out, but the careful and steady work done then undoubtedly paved the way for later dramatic discoveries. The year 1848 brought the Revolution, and for the moment the call of his beloved France was more urgent than the call of science. Caught up in the wave of exalted patriotism that was sweeping over France, he enrolled himself in the "Garde Nationale[1]," and with unwise but generous ardour laid all his hard-won savings on the "Autel de la Patrie," erected in the open street. He was glad to be in Paris in those days. "It is a great and sublime doctrine which is now being unfolded before our eyes...and if it were necessary I should heartily fight for the holy cause of the Republic."

In his personal life, too, 1848 stands out as a year of joy and of grief—joy because his chemical researches were working up to a hoped-for conclusion, and grief because, in May of that year, his mother died. The full and loving letters that passed

[1] The "Garde Nationale" was a civil militia improvised in 1789 to preserve order throughout the country. It existed for some time under the Restoration, but was suspect on account of its Liberal tendencies. In 1848 its sympathies were frankly Republican.

so constantly between Paris and Arbois had kept Louis and his family as united in affection and interest as if he still lived in the home circle, and this first loss was a crushing blow. For a time life stood still. Then the habit of work asserted itself —"when one is accustomed to work it is impossible to do without it," he had written to his sisters —and he turned thankfully to his experiments and carried them through to a triumphant conclusion.

These researches are worth a chapter to themselves, but Pasteur's later work was even more momentous and so they cannot here receive the attention they deserve. They concerned the action of the crystals of tartaric acid and paratartaric acid on polarised light and involved close observations, delicate manipulations, guided at every stage by clear thinking. The problem solved by Pasteur had baffled Biot, the famous chemist, for thirty years; but it is pleasant to be able to record that Biot, now an old man of seventy-four, welcomed the young scientist's success with generous ardour. Once convinced, by a careful repetition of the series of experiments, that the results were indeed what Pasteur claimed, Biot seized his arm and cried, "My dear boy, I have loved science so much during my life that this touches my very heart!"

Biot saw his life's work crowned by the brilliant researches of this young enthusiast, and Pasteur himself would gladly have devoted his whole energies to the "great and unforeseen road" thus opened to science; but his success had attracted

attention, and in a few months the Government made him Professor of Physics at the Dijon *lycée*.

This appointment came as a real blow to Biot. What of Pasteur's unique research work? "They don't seem to realize," he raged against the Government officials, "that such labours stand above everything else!" Pasteur, too, missed his familiar work and the inspiration of his circle of scientific friends in Paris. He now had a good deal of teaching to do, and, not sharing the easy optimism of some school-masters that their native wit, unaided by any preparation, will always carry them through, found that preparing lessons took up a great deal of time. "It is only when I have prepared a lesson very carefully that I succeed in making it very clear and capable of compelling attention. If I neglect it at all I lecture badly and become unintelligible."

The post at Dijon did not give full scope to Pasteur's special gifts and, thanks mainly to the efforts of his scientific friends in Paris, he was soon offered more congenial work as Professor of Chemistry at Strasbourg. The move to Strasbourg in January 1849 meant new life to him. He had time once more to devote to the "marvels hidden in crystallization," he found an old friend in Bertin, the Professor of Physics, "a companion endowed with a rare combination of qualities—a quick wit and an affectionate heart"—and he made new and dear ones in the family of M. Laurent, the Rector of the Academy. The moment Pasteur entered the Laurents' house he breathed again the atmosphere

of high ideals and simplicity of heart that made the home at Arbois beautiful. In this happy setting Marie Laurent, one of the young daughters, shone for Louis Pasteur more brightly than the rest. The Laurents were of higher social position and education than the Pasteurs, but, with unusual insight and generosity, did not oppose Louis' suit, and at the end of May he and Marie were married. From this time till Louis himself died, his wife was a friend and wife in one, knowing when to leave him absorbed in his work, when to encourage him to talk of it, and when to distract him from it. Without her he would never have come through triumphant to the end; his achievement was hers too.

After his marriage Pasteur went steadily on with his chemical researches. Tartaric acid is a substance in ordinary commercial use, but paratartaric, or racemic, acid was then a very rare form, and in September 1852 Pasteur set out on a quest as romantic as that of any Elizabethan explorer sailing strange seas and exploring unknown lands in search of treasure. He visited factory after factory in the hopes of discovering the rarer substance among the waste products; at Leipzig he found nothing, at Vienna he gathered that the famous acid had indeed been seen the year before, at Prague he was assured that they knew how to produce it, but found that they did not. There were other tartar-refining factories in Italy, but he had not money to take him there. Besides, his quest had failed and he was tired out.

And yet, after all, had it failed? He came home

convinced that no chemist *had* produced pure racemic acid from pure tartaric acid, but not that no chemist ever would. The problem would not let him alone. First one effort and then another gave no result; but at last, on June 1st, 1853, he was able to announce to the world that the conversion had been effected, and that chapter of his life was closed with honour and success.

This work on the tartaric acids, important as it was for its own sake, was of even greater value indirectly. Tartaric acid happens to be a product of fermentation, and Pasteur's quest for racemic acid had incidentally given him opportunities of observing the actions of ferments, and so taken him over that fascinating but illusive boundary that separates life-processes from purely inorganic reactions. By a happy coincidence, just when his interest in the problems of fermentation was aroused, his appointment as Professor and Dean of the new Faculté des Sciences at Lille sent him to live in a country of distilleries. Pasteur took a comprehensive view of his duties as Dean, for, besides lecturing to his pupils, he took them over factories and foundries, and in 1856 even organised for them a tour of the Belgian industries. His own research work was, however, still the heart and inspiration of all he did; in 1856 he was grappling with the manufacture of alcohol from beet-sugar and in 1857 he communicated to the Lille Scientific Society a paper on lactic-acid fermentation which, it has justly been said, "fixes the date of the 'New Learning.'"

LOUIS PASTEUR

To us to-day the contents of this paper seem commonplace enough. It records how Pasteur isolated the trace of greyish substance that can always be found in sour milk, sowed it on sweet milk, and proved that it turned it sour. This greyish substance he proved to be a living organism and maintained that in its absence milk will remain sweet indefinitely. Now in the middle of the nineteenth century the leading chemists, headed by Liebig, held that the chemical actions taking place during fermentation and allied changes can be explained "in terms of molecular physics" alone; and therefore Pasteur's conclusion that they cannot occur without the action of live bacteria rang through the scientific world like a challenge. For twenty years the exponents of the older view fought obstinately, but facts were against them—experiment after experiment confirmed Pasteur's view. Fermentation, decomposition, putrefaction, all are "acts of life, and in the absence of life do not take place." "A liquid really sterile, exposed to air really sterile, will remain sterile for ever," and, in that condition, will neither ferment nor putrefy. Germs are not exempt from the general law of life; they "cannot come into the world without germs, without parents like themselves"; as Pasteur himself put it, "La vie c'est le germe et le germe c'est la vie."

It happened that in 1857 the Ecole Normale was going through difficult times, and when Pasteur was asked to take over the science teaching, his old love of the place and sense of its value to the nation drew him there. This post involved tiresome

details of catering and other practical matters, and Biot raged afresh that Pasteur's time should be wasted over these petty duties and that the only room available for his research work was an icy garret. The difficulties were indeed great; and yet, in spite of them, his work was done.

Pasteur's discovery of the part played by germs in fermentation led him to hope that he might push his studies "far enough to prepare the road for a serious research into the origin of various diseases." In 1865 cholera came from Marseilles to Paris, and Pasteur and others made many experiments on the air of a cholera-ward in the Lariboisière Hospital. "Courage is needed for this sort of work," said a colleague. "Et le devoir?" Pasteur answered simply.

In this same year Pasteur began his famous studies on the diseases of silk-worms. For twenty years the silk trade had been going from bad to worse, and the practical experts were completely baffled. From 1865 to 1869 Pasteur was grappling with this problem; it was complicated by the fact that there were two diseases (pébrine and flachery) to investigate, and was rendered difficult by the hostility or scepticism of the very people whom his discoveries would benefit.

This too was a period of tragic personal loss. In June 1865 his father died; in the same year his baby girl, Camille, fell ill and died also; and in the next year typhoid carried off his daughter Cécile, then a child of twelve. His eldest daughter, Jeanne, had died of typhoid in 1859, so his cup of

sorrow was indeed full. Still he struggled on. In October 1868 his silk-worm researches were almost over when suddenly he was struck down by a cerebral haemorrhage. His brain remained clear, but one side was paralysed, and he and his friends thought that at forty-six his life's work was over. But no; gradually his powers returned, and three months later he was back at work again, shaken but safely convalescent.

A few weeks more and the silk-worm chapter of his life was closed; he had identified the two diseases, proved them to be contagious as well as hereditary, and shown how to detect and stamp them out. Writing to a friend, he stated the problem and its solution with great clearness and simplicity:

> The evil was sought for in the worm and even in the seed; that was something, but my observations prove that it develops chiefly in the chrysalis, at the moment of the moth's formation, on the eve of reproduction. The microscope then detects its presence with certitude, even when the seed and worm seem very healthy. The practical result is this: you have a nursery full; it has been successful or it has not; you wish to know whether to smother the cocoons or whether to keep them for reproduction. Nothing is simpler. You hasten the development of about 100 moths through an elevation of temperature, and you examine these moths through the microscope, which will tell you what to do.

Even in March 1869 the silk trade was still only half convinced of the absolute value of Pasteur's results. "They *are* absolute," he insisted, and, to

prove his point, sent to the sceptical Lyons Silk Commission four lots of seeds. "Lot 1 is healthy," he said, "and will succeed; lot 2 will die of pébrine only; lot 3 will die of flachery only; and out of lot 4 some will develop pébrine and some flachery." And everything he predicted came to pass. That is the story of how the silk trade was saved by an "unpractical" man of science.

In 1870 came the Franco-Prussian War. It nearly broke Pasteur's heart; he had to watch his country defeated and dishonoured and could do nothing. "Ne faut-il pas s'écrier, Heureux les morts?" he wrote in despair, on hearing that Metz had surrendered without a struggle. His friends got him out of Paris to Arbois by the cruel-kind argument, "You have no right to stay; you would be a useless mouth in the siege." He could have gone to Pisa as Professor, but would not leave France at this moment of her humiliation; through science he might perhaps help her to raise her head proudly again among the nations. The work that first offered itself arose out of his researches on ferments. He had improved French wines and vinegar and was now asked to investigate and improve French brewing. He accepted gladly, for might he not in this industry raise his beloved France above her rival, Germany? For five years he studied the problems of beer-making, but his thoughts ranged far beyond the narrow borders of his subject. The war had brought its usual crop of tragically unnecessary deaths, deaths from septic wounds and deaths from disease, and Pasteur re-

turned again and again to his old hope of discovering "the causes of putrid and contagious diseases." A few years before, Lister, the famous Professor of Surgery at Glasgow University, had begun introducing what we now call antiseptic methods into surgery. Before this time operations and wounds of all kinds were liable to become septic, and more patients died from this cause than from the actual operation or wound. Lister's work was partly based on Pasteur's but adapted to suit the needs of live patients. Pasteur had shown how to prevent putrefaction in broth by boiling it and then keeping it in "filtered air" in flasks. This method was obviously unsuitable for wounds, and Lister therefore employed carbolic acid to arrest or prevent putrefaction. The year 1870 found France unfamiliar with this wonderful new method, and thousands of wounded, whom antiseptic treatment would have saved, died; then she introduced "Listerism" into the Paris hospitals and proved for herself its saving power. This was an important step in the right direction, but Pasteur's thought probed deeper; he was convinced that each definite disease was caused by a specific germ and longed to track down and study individually these terrible enemies of mankind. "It would indeed be a grand thing," he once said, "to give the heart its share in the progress of science," and in this work more than in any other his whole being was engaged, for "the memory of the children he had lost...caused him to desire passionately that there might be fewer empty places in desolate homes, and that this

might be due to the application of methods derived from his discoveries."

The next step towards the realisation of these high and humane hopes was taken in connection with anthrax, or splenic fever, a terrible disease of sheep which at that time was destroying 5 per cent. of the cattle and 10 per cent. of the sheep of France. As early as 1839 what we now know to be the germs of anthrax had been seen under the microscope in the blood of animals which had died from anthrax, but it was not until after Pasteur's silk-worm researches that their full significance was understood. In 1863 Davaine recognised the *bacillus anthracis* as the living germ of the disease; in 1876 Koch grew the bacillus in a culture solution and with it gave anthrax to mice and rabbits; and in 1877 Pasteur himself took up the problem. Like Koch, Pasteur cultivated the disease outside the body and reproduced it in a variety of animals; from 1878 to 1880 he gave much time to studying its natural history, but at the end seemed no nearer the discovery of how to protect animals from it. This final achievement came, by chance, through his work not on anthrax but on chicken-cholera. "By chance," but not chance in the gambler's sense. "In the fields of observation," Pasteur once said, "chance only favours the mind which is prepared." His researches on silk-worm diseases and on anthrax, his knowledge of the results of other men's labours, the continuous working of his own remarkable brain, always trying to co-ordinate and predict, all these were factors in his ultimate suc-

cess. While working with a pure culture of the chicken-cholera germ, he found that it lost strength merely by keeping, and that a fowl, inoculated with this weak culture, suffered only a "passing indisposition" and *afterwards was immune from the disease even when treated with the strongest culture.*

As long before as 1796, Jenner in England had made his amazing discovery of vaccination against smallpox. Pasteur was never tired of singing his praises—"Un des plus grands hommes de l'Angleterre, votre Jenner," he called him to an English audience; but Jenner's discovery only proved the benefit of inoculation in a particular case, while Pasteur's researches seemed to point to the method's having a general application. This was entirely in line with Pasteur's own hopes and he was filled with exalted enthusiasm—"I have a lasting provision of faith and fire," he wrote to a friend at this time. He attacked the anthrax problem with fresh conviction, overcame difficulties, refused to accept failures as final and, by May 1881, was sure enough of his methods to challenge the "unbelievers" to a combat as dramatic as Elijah's with the priests of Baal.

"Take," he said, "50 sheep, inoculate 25 with a weak culture of the anthrax virus, and then, some days later, inoculate the whole 50 with a very virulent culture. The 25 unvaccinated sheep will all perish, the 25 vaccinated ones will survive."

Even some of Pasteur's disciples were a little uneasy at this uncompromising challenge, but he had "faith and fire" enough for them all; he was

determined to win, in the cause of truth, a decisive victory.

On May 5th Pasteur met, at the farm of Pouilly le Fort, near Melun, a large number of his opponents—farmers, doctors and, above all, veterinary surgeons, exchanging sceptical looks and jokes as befitted the occasion. On this day, twenty-five of the sheep received their first injection with a weak culture. This done, the mixed assembly collected in the hall of Pouilly farm to hear what Pasteur had to say for himself. He was a hot-tempered man and at times lost patience with his opponents, but to-day the greatness of his cause lifted him above petty irritation and "in clear, simple language, meeting every objection half-way, showing no astonishment at ignorance or prejudice, knowing perfectly well that many were really hoping for a failure, he methodically described the road already travelled, and pointed to the goal he would reach."

During the next twelve days all the sheep remained well. On May 17th the twenty-five sheep were again inoculated, this time with a stronger virus. This, if given without previous treatment, would have killed about half of them, but Pasteur's experiments had led him to expect that, given in this way after inoculation with weak virus, it would have no bad effects at the time and yet would increase resistance to any later incursions of the disease. The sheep were watched anxiously for the next fortnight, but not one of them sickened. In Pasteur's scientific and home circles the interest

was intense, and wherever farmers and veterinary surgeons met there was excited discussion.

On May 31st a great crowd assembled for the final inoculation. Pasteur's opponents were not all generous and some suspected trickery—perhaps the strong virus was weaker at the top and this would be injected into the inoculated sheep and the stronger into the untouched sheep. This clique created an atmosphere of fussy interference; one man "shook the virulent tube with real veterinary energy"; another suggested that a larger dose than had been intended should be given; others asked for the vaccinated and unvaccinated sheep to be treated alternately. Pasteur showed no impatience, but did all that was asked of him. His calmness half shamed his critics and won over some waverers to his side. Still, friends and foes alike must bow to the decision of fact, and an appointment was therefore made for June 2nd, for a final inspection of the sheep.

On June 2nd Pasteur's opponents, keyed up now to an even greater pitch of excitement, kept their last appointment with him. "The carcases of 22 unvaccinated sheep were lying side by side," two others were dying and another sickening. The twenty-five inoculated sheep were all quite well. As Pasteur walked into the farmyard, he was greeted by a generous burst of cheering from the entire gathering. He had won for truth a complete and final victory.

In 1880 Pasteur had begun his work on rabies, or hydrophobia, and it progressed side by side

with his anthrax researches. In this case, however, he was handicapped by his inability to find the germ, by the length of the incubation period of the disease, and by its extreme deadliness. For himself he did not mind risks—one day he even sucked up some saliva from the mouth of a mad dog into a tube, but he dreaded taking the final step from inoculating animals to inoculating man. The popular idea was that the saliva was the chief seat of the disease; but Pasteur thought that it was rather in the brain and spinal cord and, in particular, in the *medulla oblongata*, the part of the cord nearest the brain. He proved that inoculation of a dog or rabbit with a measured quantity of the medulla of a dog which had died of rabies was more certain to produce the disease than inoculation with saliva. But even this method gave an occasional failure, and still the incubation period was too long. Pasteur was sure that the effect would be more rapid if the virus were put on the brain of the animal, but he had such a dread of causing pain that he shrank from the necessary operation of trephining a dog's skull. One day, however, when he was out, his assistant Roux performed it. When Pasteur was told, he was most distressed: "Poor thing! His brain is no doubt injured, he must be paralysed!" Fortunately this was not the case; Roux fetched the dog and he trotted round the room, sniffing at one thing after another like any normal undamaged dog. This method of inoculation always gave a positive result, and the latent period was shortened so as to be never more than twenty

days. Here was definite progress, but for Pasteur it was not enough; he must get the period absolutely fixed, he must know the exact day on which "the disease should flare up." This result too he achieved by passing the virus through a series of rabbits; the disease developed more quickly as the inoculations proceeded, but, when the period had reached six or seven days, it became fixed. The virus thus obtained was stronger than that obtained from a case of rabies and would always cause death[1].

Now came the problem of definite protective treatment. The virus of rabies, like that of anthrax, weakens with mere keeping and after fourteen days is quite harmless. Making use of this fact, Pasteur was able, by inoculating rabbits on consecutive days, to collect a complete series of dried spinal cords, containing the virus at all degrees of strength up to full virulence. He next inoculated dogs with a fixed quantity of the 14-days' cord, then with the 13-days' cord, and so on up to the fresh virus. Dogs treated in this way were unharmed by the bite of a mad dog or even by the trephining inoculation[2]. A few months later, Pasteur completed the work, as far as dogs were concerned, by proving that, *even when inoculation followed, instead of preceding, the bite of a mad dog* it protected the patient from the consequences.

[1] Humane people will be relieved to know that rabies produces in rabbits only a painless kind of paralysis.

[2] When Pasteur had proved this fact to his own satisfaction, he asked that his results should be verified by a commission. In May 1884 a Rabies Commission was appointed and further experiments, performed for their benefit, confirmed Pasteur's conclusions.

"I take two dogs," he wrote in September 1884, "I have them bitten by a mad dog. I vaccinate the one, and I leave the other without treatment. The latter dies of rabies; the former withstands it. But, however I should multiply my cases of protection of dogs, I think that my hand will shake when I have to go on to man."

For nearly a year, Pasteur tested his method with dogs and other animals; and then, in July 1885, a human patient was literally thrust upon him. This was Joseph Meister, a little Alsatian boy of nine, badly bitten in fourteen places and found covered with blood and saliva. Later in the day the dog had bitten his own master, had been shot by him, and had been found to show indications of rabies. The child's wounds had then been carbolised, twelve hours after the attack. Pasteur never lost sight of the human side of a question in his absorption in the scientific. When Madame Meister arrived in Paris, with her poor wounded child hardly able to walk for pain, he was greatly distressed. He at once took rooms for them and then went off to consult Vulpian, a medical professor and a member of the Rabies Commission, of whose judgment he had formed a high opinion. On hearing details of the case, Vulpian strongly advised the use of anti-rabic treatment. When Pasteur hesitated, he expressed the opinion that the results obtained with dogs justified him in foreseeing the same success with men, and further that, as there was little chance of saving the child by any other method, it was a duty to try the new

treatment. Pasteur agreed, and the inoculations began. After the first slight prick for the first inoculation, little Meister was no longer frightened, and, as he recovered from his wounds, became thoroughly happy and at home. He loved the laboratory animals—chickens, guinea-pigs, rabbits, and white mice—and easily persuaded Pasteur to give him some as pets. *He* had no fears, but, as the inoculations increased in strength, Pasteur's uneasiness grew. Suppose, after all, he were to fail? His nights were broken and his days restless. "Give me a kiss, dear Monsieur Pasteur," ordered the child, as he ran off gaily to bed after the last injection. That night he slept as usual peacefully, but for Pasteur there was no sleep. A horror of great darkness descended on him, the remembrance of all his successful experiments brought him no reassurance, he saw only "the dear lad suffocating in the mad struggles of hydrophobia." A terrible night; but at last it was over, and, with the day, hope and joy returned, for the boy was well. This first human case was a complete success. Shortly after, a young shepherd, Jupille, was treated. He had rescued some children from a mad dog and had been himself badly bitten before managing to kill it. To make things worse, he arrived in Paris six days after the attack; yet inoculation saved him also.

The news of the successful treatment of these two cases rang through the world, and in the next six months 350 patients were treated. The only failure was a little girl, Louise Pelletier, who was

not brought for treatment till thirty-seven days after being bitten. In March 1886 nineteen Russians, badly torn and mutilated by a mad wolf, were brought by their doctor to Paris. The bite of a mad wolf is even more deadly than that of a mad dog, and it was fifteen days since the wounds had been inflicted. It was almost certainly too late, but Pasteur could not deny these forlorn fellow-creatures even the faint hope of life that his treatment offered. Of the number, only three died—a really surprising result, considering the conditions; yet some of Pasteur's opponents seized on these deaths as evidence against his method. Nothing but hard facts will convince the wilful sceptic, but these fortunately piled themselves up steadily in support of the treatment as time went on. In 1886, out of 2671 people treated, only 25, or less than 1 per cent., had died. Statistics collected at this time showed that the proportion of deaths after bites from rabid dogs was 40 per cent.; so, on this estimate, Pasteur's method saved about 1000 lives in the first year. Conviction of the value of inoculation as a protection against rabies grew steadily in the minds of unprejudiced doctors and men of science, and a Commission, appointed by the Académie des Sciences, unanimously voted that subscriptions should be asked for in France and abroad to found an "Institut Pasteur" in Paris for the preventive treatment of hydrophobia.

In November 1888 the Pasteur Institute was opened, and through it Pasteur's work lives on. He himself was now growing "weary and old with

service" and was glad to let his work pass gradually into the hands of willing and able disciples. Every inspired scientist must feel about his work, as Pasteur did of his, that "the breath of Truth is carrying it towards the fruitful fields of the future," but all are not as happy as he was in living to see his work come to fruition.

Little by little, his interests and powers slipped from him, until, on September 28th, 1895, he passed peacefully away. Death came thus quietly and late; but had it come early and broken his work in two, his life would still have been, in the deepest sense, complete, for he had his own high ideal and followed it to the end. To him service to man was service to God: "Blessed is he who carries within himself a God, an ideal, and who obeys it: ideal of art, ideal of science, ideal of the gospel virtues, therein lie the springs of great thoughts and great actions; they all reflect light from the Infinite."

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